Biomass Energy Conversion Technologies in China: Development and Assessment

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MOA/DOE Project Expert Team

This book is written and edited based on the output of joint research project "Evaluation of Commercialization of Biomass Energy Conversion Technologies and Their Market Oriented Development Strategy" between Ministry of Agriculture of China and Department of Energy of US. The project has been supported and helped by both governments.

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Part One Overview

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Chapter 2 ZHANG Zhengmin, XIONG Chengyong, CAI Changda

Chapter 3 DAI Lin, SUN Li

Chapter 4 ZHANG Zhengmin, CAI Changda

Part Two Case Study

Chapter 5 DAI Lin, LU Zengan

Chapter 6 SU Mingshan, JIN Yao, ZENG Banglong

Chapter 7 QU Feng, WANG Gehua

Chapter 8 SHI Jingli, CAI Changda

Part Three Users Survey Analysis

Chapter 9 DAI Lin, LIU Xiaofeng, LU Zengan

Chapter 10 DAI Lin, LIU Xiaofeng, ZENG Banglong

Part Four Appendix

Appendix 1 DAI Lin

Appendix 2 ZHANG Zhengmin

With Mr. LOU Zhentao and Mr. Ralph Overend going over the text; and Mr. LIU Xiaofeng laying out the pictures,tables, and articles.

CONTENTS

Preface

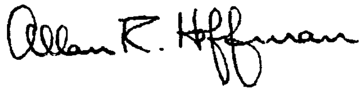
I am Allan Hoffman, Acting Deputy Assistant Secretary for the Office of Utility Technologies of the U.S. Department of Energy (DOE). Recently, I led a DOE team to China to review the progress of bilateral cooperation under the Energy Efficiency and Renewable Energy Protocol signed in 1995. I must tell you how pleased I am to see that China has made considerable progress in the use of renewable energy and attention to environmental issues. I also want to congratulate China's Ministry of Agriculture (MOA) for its efforts to develop rural energy.

The MOA is the implementing agency for Annex I of the Energy Efficiency and Renewable Energy Protocol, which supports The Integrated Rural Energy Construction Program in One Hundred Counties in China. To date, DOE is pleased with joint progress made in three areas: (1) the Gansu Solar Home System project has deployed photovoltaic household systems in 300 homes and 10 schools, with another 300 systems planned by the end of 1998; (2) a comprehensive biomass technology and resource assessment is ready to be published; and (3) a socioeconomic and technology assessment of rural electrification applications is under way.

I applaud that the MOA plans to publish the reports, of which this is the first one in English and Chinese. The publication of those reports represents not only a major milestone in joint activities between the DOE and MOA, but also the foundation for continued U.S.-China cooperation with potential benefits for both countries. China is fortunate to have abundant biomass resources that can be efficiently used as a CO_2-neutral power source, a critical part of China's energy sustainability and pollution prevention efforts.

The DOE would like to gratefully acknowledge the work of the MOA during the development of these publications and anticipates cooperating with the Ministry on future projects. I view our cooperation with China as very important, particularly in renewable energy projects, which can play an important part in China's response to global climate change. This cooperation will also assist China in achieving its Agenda 21 goal of sustainable energy development. Also, the potential market for U.S. renewable energy products and services in China is very large, and joint activities under the Protocol are important entry points for U.S. companies into the

Chinese market. The data in these reports will be useful to the renewables industry and serve to demonstrate the enormous potential of biomass as a sustainable resource.



Allan R. Hoffman
Acting Deputy Assistant Secretary
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Preface

China, a rapid developing agricultural country, faces the double pressure of economic growth and environmental protection as it enters the 21st century. This period presents an opportunity to transform traditional ways of energy production and consumption and explore and utilize biomass energy and other renewable clean energy resources. Clean energy resources would allow for a sustainable development of the national economy, without sacrificing environmental quality.

According to an old Chinese saying, there are seven things to gather while the door is open: fuel, rice, oil, salt, soy, vinegar, and tea. This means fuel is the primary necessity for a family. At this stage in China's development, exploration and use of biomass energy resources have special and important significance.

First, China has a large population, 70% of which lives in rural areas. The annual rural energy consumption is more than 600 million tons of coal equivalent, and one-third of that amount comes from biomass resources. Second, in China, 65 million people live without electricity; 70 million experience shortages of cooking fuel; and 120 million face the threat of desertification. In addition, inappropriate exploration and utilization of biomass energy has caused ecological deterioration and soil erosion. Third, in areas with rapid economic growth, farmers have transferred their energy consumption to commercial sources such as coal, oil, and electricity, and large amounts of crop straws and stocks are now directly burned in the fields. This has not only caused resource waste and environmental pollution, but has also intensified the demand for conventional energy supplies and has caused social problems. Thus, many believe that the Chinese government should support biomass energy exploration and utilization, as it benefits nature, households, the state, and the world.

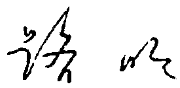
China's Ministry of Agriculture (MOA) and other relevant departments have made biomass energy exploration and utilization a priority. During the 1970s, China implemented many research projects and biomass energy utilization demonstrations. Since the 1980s, R&D to improve biomass energy conversion technologies has been listed in the National Program under key science and technology projects. Some large to medium biogas projects in husbandry farming, biomass gasification systems fed by crop straw, and biomass power generation have shown notable progress.

However, a large gap exists between the current world level and the domestic level of biomass energy exploration and utilization. This is especially true when considering the industrialization of technology and equipment. Issues remain such as how to commercialize biomass energy resource, how to accelerate the industrialization of biomass energy conversion technologies, and how to develop the huge potential market in China. These issues have drawn interest not only from China's government, science and technology, and industrial sectors, but also from the U.S. government and industrial sectors. Collaborative projects between our Ministry and the U.S. Department of Energy (DOE) to explore renewable energy demonstrate the level of interest.

It was my pleasure to meet in Beijing with Dr. Allan Hoffman, Deputy Assistant Secretary, U.S. DOE, and his delegation. We have reached a consensus that rural energy construction will advance the pursuit of sustainable development in coping with conditions in China. As we enter the new century, we will make efforts to improve the rural areas in China and throughout the world.

These three books, prepared collaboratively by MOA's and DOE's team of project experts, are the products of successful cooperation between our agencies on a study of biomass resources and biomass energy conversion technologies. I believe these research results will provide valuable reference information to government, science and technology, and industrial sectors on both sides, and will contribute to the important development of biomass energy technologies in China.

Thanks to all of you, the contributors, for your great effort.



Lu Ming
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Introduction

Biomass resource, the energy resource for human being since the ancient time, has been playing very important role along with the social development of human being. It is one of the basic elements of natural ecological system in terms of environment view point with no contribution to the global warming during its energy conversion. n China, biomass energy accounts for more than 15% in the mix of energy consumption in recent years.

Chinese government has attached high importance to the development and utilization of biomass energy resource, and conducted long and widely R&D of high and latest biomass energy conversion technology application in the National Program for Key Science and Technology Projects. Meanwhile, Chinese Government has been developing various type of collaboration and activities with foreign governments and international organizations to explore the market of biomass energy resource and its conversion technologies. On February 23, 1995, Ministry of Agriculture of People's Republic of China and Department of Energy of US signed the agreement of "For developing cooperative activities in the area of renewable energy under the hundred counties integrated rural energy development program in China between DOE, US and MOA, P.R. China" as Annex 1 under "The Protocol for Cooperation in the Field of Energy Efficiency and Renewable Energy between The DOE of US and State Science and Technology Commission of P.R. China." In 1996, under this agreement, both sides decided to collaboratively work on the issue of commercialization of biomass energy conversion technologies and their market-oriented development strategy, aimed to identify the commercial potential of advanced technology and its field, design the respectively policy and strategy for investment and market-oriented development, in order to accelerate the development of industrialization and commercialization of biomass energy technologies, through the assessment of biomass resource availability, the analysis on obstacles of technology development, and pilot research and evaluation of typical demonstration project.

The period of this joint project, divided into two phases, is 3 years. Phase 1 is from July, 1996 to July, 1998, Focusing on the availability and logistics of biomass, evaluation of the status quo and developing bioenergy technologies, case studies, and development of a market-oriented development strategy for biomass in China. It is aimed to undertake the pilot research and demonstration projects of bioenergy technologies for phase 2 based on the output of phase 1.

In order to successfully implement this project, the Energy Research Institute of State Development Planning Commission, and National Renewable Energy Laboratory were nominated as the implementing agencies by MOA of China and DOE of US. The project expert team was established joined with the related specialists from relevant agencies, institutions, and enterprises to conduct the different tasks in the project.

Based on the joint effort made by the experts from both sides, the work for phase 1 has been initially finished so far. In order to provide the better and efficient service to the national economic construction and society, it has been agreed by both sides to publish the reports with a bilingual text into 3 books titled “Assessment of Biomass Resource Availability”, “Biomass Energy Conversion Technologies in China: Development and Assessment”, and “Design for Market-oriented Development Strategy of Bioenergy Technologies”. A CD-ROM would be also attached to each book with the content of the three books. The great support and assistance have been come from Department of Environmental Protection & Energy, and Department of International Cooperation, Ministry of Agriculture, Department of Industry, Ministry of Science and Technology(ex-State Science and Technology Commission) , Energy Research Institute, State Development Planning Commission, the provincial and local rural energy offices, and Department of Energy, US and National Renewable Energy Laboratory along with the project implementation. Here we would like to thank Mr. Wang Xiwu, Mr. Zhang Guozheng, Mr. Li Baoshan, Mr. Hu Yanan, Mr. Gao Shangbin, Mr. Zhou Fengqi, and Mr. Li Junfeng from Chinese side, and Mme. Lee Gerbert, Mr. William Wallace, and Ms. Christie Johnson for their great help.

PART ONE OVERVIEW

CHAPTER 1 The Development and Assessment of Biomass Energy Conversion Technology in China

1.1 Special Significance of the Use of Biomass Energy in China

1.I.1 Biomass is the fourth largest energy resource after coal, oil, and natural gas, which plays a very important role in the energy system.

Biomass has always been one of mankind's most important energy resources. In light of its energy equivalent, it is the fourth largest energy resource after coal, oil, and natural gas. In the world's energy consumption, biomass takes up 14% of the total energy consumption, but in developing countries, it takes up more than 40%. Biomass energy in its broad meaning includes all energy which takes biomass as its carrier, and thus is renewable. It is estimated that the heat equivalent of the world's aquatic and terrestrial biomass is around 3×10^{21} joules, which is 10 times the world's present total energy consumption. Some experts predict that biomass energy will occupy a decisive position in the energy structure in future. Biomass produced through new processes will take the place of fuel mainly in the area of daily life, heat supply and electricity generation.

There is an abundant biomass energy resource in our country. The energy resource in rural discards (e.g., stalks) comes to 308 million TCE every year. The resource of firewood is 130 million TCE. Together with excrement and city waste, the total energy resource may be more than 650 million TCE, which is nearly half of the total energy consumption of the whole country in 1995. With the coming of the 21st century, mankind is faced with the twofold pressure of developing economically and protecting the environment. Thus it is of great significance to change the method for the production and consumption of energy by way of using modern technology to exploit and use renewable energy resources, including biomass energy to establish a sustainable resource system, promote the development of the social economy, and improve the environment.

1.1.2 There are 900 million people living in rural areas in China, of which 100 million are without electricity and 170 million face the threat of desertification

In the countryside of China, the basic traditional energy consumption demand is still for cooking with crop stalks and firewood as the main energy resources. And for the most part the method is direct burning, which has a very low conversion rate. With the development of the rural economy and the improvement of the rural life, much change has taken place in the traditional energy consumption (refer to Table 1.1). In 1995 the commodity energy in rural area came to 70% of the total energy consumption. The rest went to biomass energy and other renewable energy. Still there are 110 million people who have no electricity supply, 70 million suffer from the severe shortage of firewood for cooking, and another 170 million people suffer from the threat of their land being reduced to desert. Moreover, the cost of the environment can not be neglected. First, the environment has been severely destroyed, which results in the increase of land area of from 1.5 million km^2 in 1950's to 3.67 million km^2 being washed away. Second, the disorderly use and waste of biomass resources increases pollution. Third, the environment quality deteriorates with the rapid development of village and town enterprises.

Table 1.1 Change in the energy consumption in rural areas in 1979 and 1996 (Unit: MTCE)

Type	1979	1996
Coal	60	259.39
Petroleum products	14.27	46.28
Electricity	31.2	93.32
Biomass	221.7	220.43
firewood	103.7	99.33
stalks	118	119.97
others (biogas, solar energy, etc.)		1.13
Rural electricity generator (GW)	142.5	358.26
Total amount of the rural population (million)	800	860
Average amount of commodity energy in rural area (TCE/head)	0.14	0.47
Number of the population without electricity (million))	450	110
Population in bad need of fuels (3-6 months) (million)	420	70

Source: Report on the development of China's energy, 1994. "Collection of the Statistical Data of the Rural Energy in 1996," compiled by the Department of Environment and Energy Ministry of Agriculture, P.R. China.

1.1.3 Biomass is a low-carbon energy resource, which will play a very important role in better restructuring the energy consumption structure with fossil fuel as its main source in China.

The common feature of the energy production and consumption structure in China is: coal takes up an absolute leading position for a long time in the energy consumption structure, very often more than 70%; high-quality resources such as petroleum, natural gas, and hydroelectricity take up only about 25%. While the energy supply is increasing, the proportion of high-quality energy resources in the consumption structure is dropping. With a view to the energy consumption structure in different areas, due to the difference in the level of economic development between the coastal area and the inland, the energy structure in the coastal area is continuously improving as it has a better transportation and environmental protection. Take Guangdong for example, in 1995 petroleum and electricity took up 43.6% while coal only took up 56.4% of the energy consumption. In light of the consumption of different energy forms, the increase of electricity and liquefied petroleum gas is rapid. In 1995 they increased 2 times and 9.3 times, respectively, compared to 1990. While the consumption of coal increased only 1.4 times, the wood fossil fuel still dominated the energy structure.

After the energy crisis, researchers in developed countries have developed technologies for converting energy trees to take the place of mineral fuel because biomass is abundant and renewable, and it contains less sulfur and ash but more hydrogen than coal and accordingly it is cleaner. If it is changed into gas or liquid fuel, it is not only clean, but also convenient. Furthermore, in the course of burning, mineral fuel gives out CO_2, which keeps accumulating in the atmosphere. In the beginning of the industrialization, the density of CO_2 in man's breath took up 0.28% of the volume of air. But in 1980 the density rose to 0.34%. It is estimated that by the beginning of the next century, it will reach 0.56%. The ever increasing density of greenhouse gases in the atmosphere leads to a warmer climate. As biomass is a low-carbon fuel and absorbs CO_2 in its production, it becomes a sink for the greenhouse gases. So for the cooperation with the universally united action to eliminate the greenhouse gases, it is of great significance to devote major efforts to exploit biomass energy resource for the improvement of the fossil-dominated energy structure, especially for the supply of a clean and convenient energy in line with the local conditions in rural area.

1.2 The Development of Different Types of Biomass Energy Conversion Technology in China

1.2.1 Types of the biomass energy conversion technology in China

The use of biomass energy can be roughly classified as the technology of direct burning, physical conversion technology, biological conversion technology, liquefaction technology, and conversion technology for solid waste (see Fig. 1.1). According to the purpose and goal of the project, the research will concentrate on

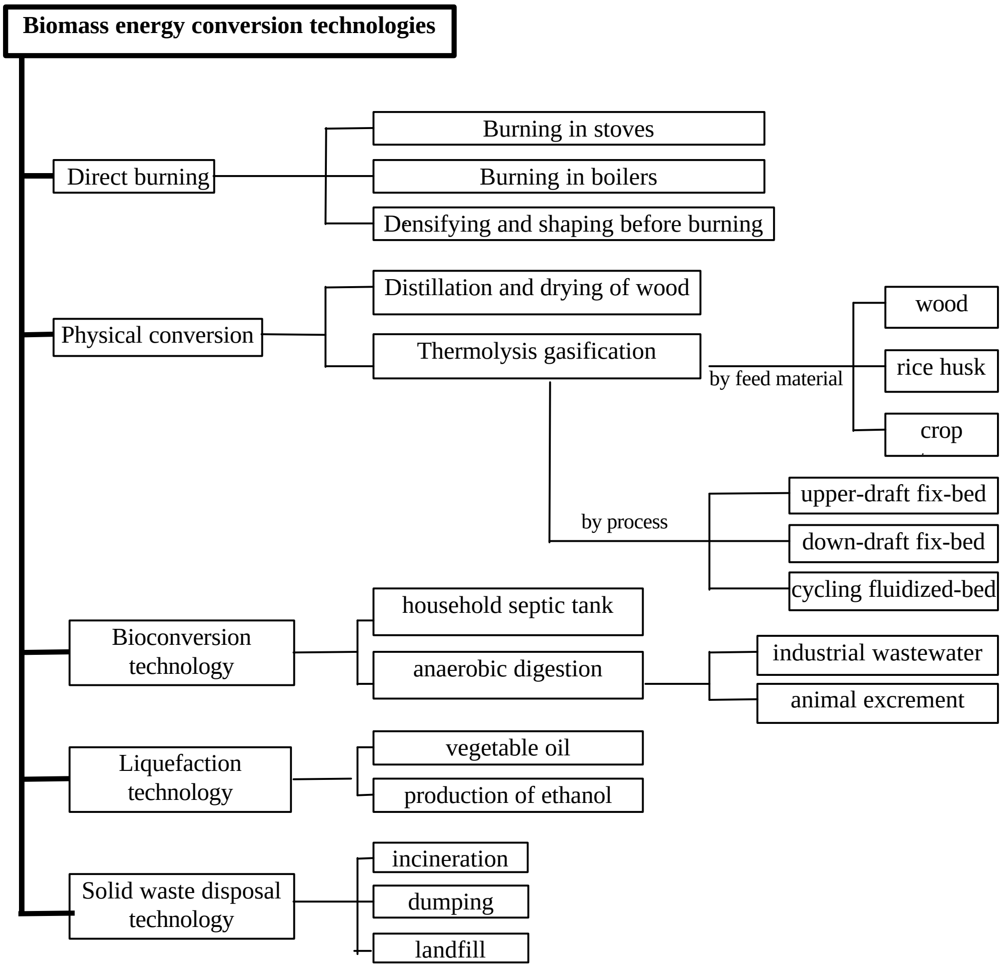


Figure 1.1. Classification of biomass energy conversion technologies

the following three conversion technologies: technology for large- and medium-scale biogas projects on animal farms; technology for thermolysis gasification of raw material such as stalks; and technology for the treatment of city solid waste (garbage).

1.2.2 History and changes in the technology for large- and medium-scale biogas projects on animal farms

The biogas projects on animal farms refer to the complete set of engineering equipment for anaerobic digestion with animal excrement as its raw materials for the production of biogas and the harness of the environment pollution. In China biogas projects are classified into three groups according to size (see Table 1.2).

Table 1.2 Classification of biogas projects

Scale	Volumetric capacity of digester (m^3)	Total volumetric capacity (m^3)	Daily biogas production (m^3/d)
Large scale	>500	>1,000	>1000
Medium scale	50-500	50-1,000	50-1,000
Small scale	<50	<50	<50

The development of biogas projects on large- and medium-scale animal farms in China began in the late 1970s. By now it has a history of 20 years. The development is closely related to the development of the size and the level of concentration of the breeding industry in China and is related to the concern of the whole society over the environment protection. The development of biogas technology can be roughly divided into three periods:

- The first period lasted from the late 1970s to the mid-1980s. The biogas projects on animal farms during this period were mainly built for the production of biogas to alleviate the severe energy shortage in rural area. As large- and medium-scale animal farms were not common, the materials for digestion of the projects were taken from animal excrement and sometimes from crop stalks. The rectangular or cylindrical digester was the major part in the project and was usually built underground. The digestion was performed under normal temperature and the volumetric biogas production only came to about $0.2m^3/m^3$ per day. The digested residue was used as fertilizer with no treatment.

- The second period lasted from the mid-1980s to the early 1990s. During this period research was performed on digestion technology, construction of the digester and counterpart equipment in view of the problems in the large- and medium-scale biogas projects. The biogas projects were normally and steadily operating. The volumetric yield of biogas under normal temperature approached $0.5m^3/m^3$ per day. The biogas projects on the Mianyang breeding stock farm in Sichuan and the Dengta chicken farm in Hangzhou are examples. Meanwhile advanced technologies were introduced from abroad and training and administration were enforced, which greatly promoted the technology for biogas projects. The promotion can be seen in the following:

Various types of technologies for anaerobic digestion had been employed, such as upper fluid, anaerobic filter, anaerobic contact, etc. Stirring devices were commonly adopted. Some projects used mid-temperature for the digestion to ensure the annual average gas production. The digesters were mostly built on the ground and concrete was taken as the construction material. The stirring became more and more standard. Pretreatment had been paid attention to. For example, there appeared special sedimentation tank, mixing boxes and dreg-filter, etc. Special equipment for biogas storage and mostly wet tanks were adopted, and equipment for desulfurization of biogas was put into use. The issue that special attention should be paid to the benefit of the environment protection at the same time with the exploitation of energy resources, and that comprehensive utilization should be adopted was for the first time put forward. Administration was enforced. The design of most projects was standard. On-the-spot check before acceptance was performed after the construction of the projects and collections of drawings for reference had been made.

- The third period began in the early 1990s and lasts till now. The progress in this period can be seen in three aspects: (1) more stress is put on the environment benefit of the projects; (2) the economic benefit of the projects is increased through comprehensive utilization; and (3) the comprehensive benefit of the projects is realized by way of excellent design, construction, and brilliant counterpart equipment, e.g., biogas projects on Xizi breeding farm in Hangzhou and Tangwan breeding farm in Shanghai.

Table 1.3 summarizes the goals of the biogas projects in different phases, the raw materials, and the digestion technologies.

Table 1.3 Historical periods of the development of anaerobic digestion

Time	1960s-1980s	1980s-1990s	1990s
Object	Energy	Energy + environmental protection	Energy & environmental protection & economic comprehensive utilization
Types of the materials	excrement + crop stalks	excrement	same as in the left
Technology for digestion	batch process	upper fluid, anaerobic filter, anaerobic contact	same as in the left & separation of solid and liquid
Temperature for digestion	normal temperature	normal temperature mid temperature	same as in the left
Rate of production ($m^3/m^3/d$)	0.2	0.5 (normal temperature)	>1.0 (mid-temperature)
Equipment for preprocess	none	have	have
Equipment for aftertreatment	none	have	have
biogas purification	none	have	have
Equipment for biogas storage	none	have	have

1.2.3 Development and background of biomass gasification conversion technology

Biomass gasification is a thermochemical process technique that can convert solid biomass materials to convenient, clean and combustible gas through pyrolytic reaction. After many years' research, a lot of experiences, both in theory and practice, have been accumulated, and many achievements gained. As for gasifiers, there are mainly three types: fixed-bed reactor (including up-draft and down-draft gasifier), fluidized-bed gasifier, and airflow (whirlwind) bed. Based on the research history, it suggests a positive trend in scale of gasifier. Reaction dielectrics include air, oxygen-hydrogen, air/steam, oxygen-hydrogen/steam, etc. Recently researches mainly concentrate on cycling fluidized-bed and high-pressure gasifier with catalyst. The former accounts for large-scale devices, while the latter deals with synthetic feedstock gas with high hydrogen content. Advanced technical level on the field has been mastered by many countries such as Sweden, the United States, Italy, and Germany. In recent years, the United States had a breakthrough in biomass pyrolysis gasification, and researched and manufactured a set of biomass comprehensive gasification devices - biomass gasification set with gas turbine generation system - so that it displayed a technical pattern for large-scale generation. The development of Stirling engine makes it possible to use soft woody biomass with low caloric value and high tar content as the heat source to drive the small generator. It is an attractive technical means to develop biomass, but still is not beneficial for commercial development. Biomass gasification devices aboard generally are large-scale, of high automation degree and complex technique, and concentrated on generation and thermal application. Their gasification efficiencies can reach 60-90%, and combustible gas has a caloric value of 17-25MJ/m^3.

China began very early to research biomass pyrolysis gasification. During the 1950s energy shortage, it began to use gasifiers to drive vehicles, rural drainage, and irrigation machines. There had formed some approved products. A set of timber-distillation production line was imported from Poland. For wood chip-fueled gasification technology, it had been used to produce gas to drive automobiles as earlier as the 1940s. Now it has been developed to cycling fluidized-bed gasifier from layer-mode gasifier with an improvement of gasification intensity of over 10 times. In the 1960s, the Institute of Forestry Chemical Industry, Chinese Academy of Forestry Sciences completed a half-mechanized industrial device with an annual disposal capacity of 3,000 m^3, using part-oxygenation method.

In the early 1980s, race husk-based gasification device was developed in China, using a down-draft fixed-bed gasifier. It formed, finally, a series of products with a variable volume from 60 kW to 160 kW, which were applied in the food industry or exported. Model ND-600 biomass gasifier, using wood shavings, wastes, and chips as feedstock and developed by the Chinese Academy of Agricultural Mechanization Sciences, had been disseminated to tens of timber process factories. The Dalian Academy of Environmental Sciences had carried out the research and test about distillation gasification. After the 1990s, Chenglingji Food Garner in Hunan Province built a rice husk-fueled power generation station, which burns rice husks to drive steam turbine.

The research for crop stalk-based gasification technologies started later, from the mid-1980s. It aimed at building centralized gas-supply system for rural living. The Research Institute of Energy, Shandong Academy of Sciences developed a down-draft fixed-bed gasifier set. It can convert crop stalks to combustible gas with low caloric value. After cleaning the particulate and tar, the gas is delivered to rural households for cooking through centralized supply pipeline networks in a range of natural village. The feedstocks include the stalks of corn, sorghum, cotton, soybean etc. and woody wastes such as wood branch, wood chips, parings, bark, etc. The down-draft fixed-bed gasifier has a gasification temperature of over 1,000℃ and a gasification efficiency up to 72-75%. The gas productions with a caloric value of

4,000-5,200 kJ/m^3 of two models are respectively 200 m^3/h and 500 m^3/h. Now the models have been demonstrated and applied in Shandong Province and rural areas in other northern provinces.

The Chinese Academy of Sciences (CAS) has carried out many experiments on cycling fluidized-bed gasification and the equipment. The Guangzhou Institute of Energy Conversion developed a cycling fluidized-bed gasifier using tiny woody powder produced in the process of plywood as feedstock, and meanwhile did some research about the principle of gasification reaction. The equipment has consecutively operated for over 4 years in Zhanjiang plywood factories, and has been disseminated to Sanya of Hainan Province and the Wuyishan wood factory. The gasifier has a gasification intensity of over 2,000kg/m^2/h, a tenfold improvement over the fixed-bed gasifier. The caloric value of gas is also improved by 40%. All these lay a good foundation for long-term and consecutive operation, and large-scale application of gasifier. Furthermore, there still carried out an “Eighth-Five-Year” technical and scientific key task, namely “Research on biomass pyrolysis gasification technology and its development.” It was undertaken by the Institute of Chemistry and Metallurgy, CAS, and the Institute of Energy and Power, Chinese Academy of Agricultural Mechanization Sciences. The research results show that for biomass pyrolysis gasification recycling fluidized-bed, its technical indices have reached the requirement. The mid-caloric value of gas is 10.9-12.9 MJ/Nm^3 (2,600-3,080 kCal/Nm^3), gas production over 83 Nm^3/h, gasification efficiency 62.8-65.3% and conversion ratio of carbon is over 74%. However, the research was just in the initial stage while not be pushed into industrialized stage because of shortage of research funds and some technical problems. Table 1.4 shows the situation about the application of biomass gasification technologies in China.

1.2.4 Development and Change of Municipal Solid Waste Disposal Technology

The municipal waste disposal is lately started in China, and the capacity of solid waste harmless disposal is still inferior. Now the common technologies are dump, fertilization, landfill, landfill-biogas-power-generation, and incineration-thermal-power-generation. In recent years, the capacity and the rate of harmless disposal has increased significantly with the efforts of considering the local situation, utilization of research achievement during the “Seventh-Five-Year-Plan” and the “Eighth-Five-Year-Plan,” and a combination of domestic and foreign technologies

Table 1.4 Present status of application for biomass gasification technologies in China

Type	Diameter of Gasifier (mm)	Gasification Intensity ($kg/m^2/h$)	Power (MJ/h)	Usage	Research Unit
up-draft	1,100	240	2.9	thermal supply for production	Guangzhou Institute of Energy Conservation, CAS
	1,000	180	1.6	thermal supply for boiler	Nanjing Institute of Forestry and Chemistry, Chinese Academy of Forestry Sciences
down-draft	400	200	300	tea-drying	Chinese Academy of Agricultural Mechanization Sciences
	600	200	660	timber-drying	same as above
	900	200	1,490	boiler gas-supply	same as above
	700	200	900	living gas	Research Institute of Energy, Shandong Academy of Sciences
layer-type	2,000	150	160 kW	power-generation	Ministry of Commerce and Trade
down-draft	1,200	150	60 kW	power-generation	Food Bureau of Jiangsu Province
	200	398	2-5 kW	power-generation	Guangzhou Institute of Energy Conversion, CAS
cycling fluidized-bed	400	2,000	4.2	gas-supply for boiler	same as above

and funds. By 1994, 609 sets of harmless disposal plants had been built, and the harmless disposal rate reached 35.7%. At present, disposal technologies such as dump and simple landfill have been applied in most cities, some advanced measures such as harmless landfill, mechanized fertilization and incineration are also adopted in some cities.

1.2.4.1 *Landfill*

For a long-term, natural dump, natural landfill pits and land level up are the commonly adopted measures in refuse disposal in most cities in China, not only the valuable land resource is wasted, but the potential harm to environment is made.

Because the penetration fluid of landfill yard is not collected and centrally purged, it has seriously polluted the water resource and environment. In recent years, a series of advanced landfill yards was completed. Many cities such as Hangzhou, Guangzhou, Suzhou, Beijing, Chengdu, Baotou, etc. had set up comparatively harmless landfill yards in accordance with their situation. Meanwhile, the technology for collecting and using gas from landfill yards has also been developed.

As an engineering technology, the harmless landfill technology is to put refuse into a comparatively enclosed system, to reduce its influence on the surrounding environment as little as possible. So it has a safeguard system consists of a sets of strict operation procedure and corresponding technology measure.

Harmless landfill is an engineering method, in which the jeopardize to surrounding can be limited to the lowest extent through dumping the refuse into a comparatively closed system. Therefore, a complete set of strict operating rules and corresponding technical measures should be taken as guarantee. Normally, seamed development and cell separated landfill manner is adopted in a harmless landfill site to built a well infiltration-proof system. The fundamental process of infiltration treatment is “anaerobic sector→blow and separate sector→A/O biologic sector→coagulate and sediment sector.” Moreover, complete underground water collection, sewage collection, and environment monitoring systems are also equipped in the whole system. Some new landfill yards are fitted out with methane collection and power generation system and had complete effective utilization of energy. Service the period of landfill yard is determined by the volume of storage and is generally longer than 10 years. At present, landfill is the primary method of refuse disposal in China and takes up 90% of the gross disposed volume.

1.2.4.2 *Fertilization disposal*

Compared with other disposal measures, refuse fertilization developed rapidly in China with relatively high research and application level. “Dual fermentation art” has been applied since the 1980s. The process adopts obligated blow and aerobic fermentation to shorten the primary fermentation cycle to 10 days, consummate piling equipment and promote industrialization of refuse fertilization. At present, on the basis of foreign technology introduction and Chinese situation, domestic designed mechanic process line for refuse fertilization had been set up in some cities, such as Wuxi, Changzhou, Tianjin, Mianyang, Beijing, and Wuhan. Some simply equipped refuse fertilization plants are also in operation.

The technological process of refuse fertilization is as follows: pot→grab bucket crane→conveyer→drum screen→manually sieving (plastic, glass, paper etc.) → magnetic separator→first fermentation→second fermentation→relaxation screen→ hard matter removing→fertilization product.

Compared with those in industrialized countries, the technology level of refuse fertilization in China is quite low, mainly on:

- Production of refuse fertilization is carried out on low mechanical level. Fertilization is of bad quality with low fertile efficiency.
- A considerable part of fertilization is acted in simply equipped condition. Some aspects such as fermentation standard control and prevention of secondary pollution should be improved.
- Because of low content of organism in refuse compared with that of developed countries, fertilization processes are mainly in an interim manner. With the growth of organic content in urban refuse, continuous fertilization technology should be developed and adopted.

1.2.4.3 *Incineration disposal*

Incineration is ranked as one of the main measures of refuse disposal prevailing in various countries, and because of thermal energy recovery and lack of land resources to build landfill plants in some metropolises and developed regions, it becomes almost the unique choice. Incineration measure just sprang up in China in recent years. Some pilot incineration power plants have been set up in cities such as Shenzhen, Leshan, and Xuzhou. Now these plants are running well, but their scale is not large and the daily capacity only ranges from 150 t to 300 t. Comparatively large-scale refuse incineration power plants are planned to be built in metropolises of Beijing, Shenyang, and Guangzhou.

In the area of equipment and technologies of refuse incineration, China has obtained great achievements during the “Seventh Five Year Plan” and “Eighth Five Year Plan.” Partly domestic production has been realized in the manufacture of main equipment such as incineration furnace, ancillary machine, automatic control devices, refuse hoist, and air compressor, which have been successfully operated in refuse incineration plants, so the system cost is reduced greatly (see Table 1.5).

Table 1.5 Comparison of refuse disposal technologies

Item	Landfill	Incineration	High temperature fertilization
Technology reliability	reliable	reliable	reliable, with operating experience
Operation safety	comparatively good, attention to fire and explosion	Good	Good
Cite selection	difficult, geographic condition and water pollution should be considered, far away from urban district, convey distance is more than 20km	easy, can be near urban district, convey distance can be less than 10km	easy, but can't be near residential district, smell radius < 200m, convey distance is 10-20km
Land requirement	Large	Small	Medium
Requirement	No requirement	heat value >4000kJ/kg	degradable organic matter >40％
Final disposal	none	residual need to be disposed, about 10%-20% of the total refuse	non-fertilization matter need to be disposed, about 25-35% of the total refuse
product market	landfill biogas can be used for power generation	thermal and electricity	it is a little difficult to enter the fertilizer market
Energy recover	Partly	Partly	None
Resource utilization	land resource recover	some resource can be recovered by refuse sorting	for fertilizer and resource recover
Surface water pollution	maybe, prevention measure is needed	Slight pollution may occur with residual filling	Slight pollution may occur with non-fertilization matter filling
Underground water pollution	maybe, impervious barrier is needed	Slight pollution may occur with residual filling	Slight pollution may occur with non-fertilization matter filling
Air pollution	can be controlled by cover layer, gas collection etc.	when exhaust gas is not disposed properly	slight bad smell
Soil pollution	only in landfill plant	None	content of harmful matter should be controlled
Management	Fair	Good	Good
Unit investment* (Yuan/ton)	2 - 4	35 - 45	7 - 10
Operating cost (Yuan/ton)	2 - 6	30 - 35	10 - 15

* Unit investment is calculated by the total disposed refuse during the whole service period.

CHAPTER 2 Status quo and Assessment of the Technology in Large- and Medium-Scale Biogas Projects on Domestic Husbandry Farms

2.1 Status of Development and Technology

2.1.1 Status of the technology

After more than a decade's development, by the end of 1996, 460 large- and medium-scale biogas projects had been built all over the country, of which the total volumetric capacity reached 0.13 million m^3. The annual treatment of rural discard was 30 million tons and the annual biogas production came to 20 million m^3 which supplied 56,000 households with biogas. These projects are mostly located in the eastern area and in the suburbs of big cities. The large- and medium-scale projects in Jiangsu, Zhejiang, Jiangxi, Shanghai, and Beijing take up half of the projects that are in operation of the whole country, i.e. 238 digesters. This is because of the fast growth of concentrated breeding industry in these areas (see Table 2.1).

Table 2.1 Status of the biogas projects on domestic husbandry farms in China

Place	Number of digesters in operation (set)	Annual yield of biogas (1000 m^3)	House-holds with biogas (1000 households)	Installed capacity of biogas power generation (kW)	Commodity fertilizer (1000 t)	Commodity feed (1000 t)
Total	460	19,994.2	55.9	866	24.9	7
Beijing	13	133.8	16.3	0	0	0
Hebei	17	91.4	0.25	0	0	0
Liaoning	10	0.7	0	0	5	0
Shanghai	41	9,913.4	17.2	0	10.7	0.1
Jiangsu	100	1,055.3	2.54	64	0.5	0
Zhejiang	33	3,511.3	8.8	3	0	0
Anhui	13	122	0.79	0	0.3	0
Fujian	6	376.2	0.2	115	0	0
Jiangxi	51	331.4	0.9	0	0	0
Hubei	63	729.6	2.6	118	0.8	5.7
Hunan	59	917.8	4.3	235	1.6	0
Guangdong	18	422.4	0.9	173	5	0

Source: "Collection of the statistic data of the rural energy in 1996," compiled by the Department of Environment and Energy, Ministry of Agriculture, P.R. China in 1997.

2.1.2 Feature and level of the technology

In recent years biogas technology in China has significantly developed. Many breakthroughs have been made in both the research on the materials for the biogas project and the technology for digestion, and the research on the system and its counterpart equipment. The skill has been improved quite a lot.

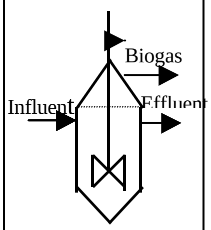
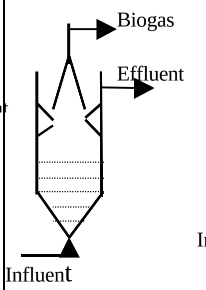
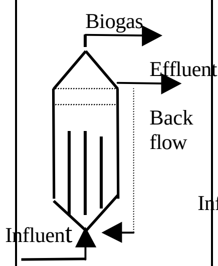
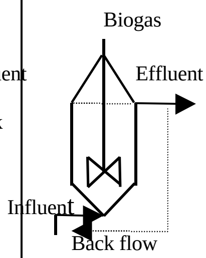
1) Various highly efficient digestion technologies and equipment have been invented and some of them have been successfully put into practical use.

Hydro-pressure biogas digesters of 50-100m^3 were mostly adopted for the early biogas projects in China. Each project consisted of several or tens of tanks. The advantage of this kind of digesters is its digestion under normal temperature. The materials for digestion need to be strictly preprocessed. They could be built under pig sties or cattle pens, which saves land. So they are still of some practical value in areas with high temperature. Their disadvantages can be seen in that it is difficult to remove the effluent, as they are underground, and it is difficult to preserve the heat; the production is low with only 0.2-0.3 m^3/m^3/d when the density of the influent is 6-7%; and moreover, the technology brings about a severe loss of sludge; there are few microorganisms in the tank and the density of the residue is uneven and difficult to control, which does not meet the modern need for a fast treatment of massive waste. Since the 1980s, digestion technology and equipment have improved in light of the weakness of the former technology. Highly efficient devices for digestion have been designed and manufactured. Table 2.2 shows some basic technical features of currently often used digestion devices for biogas projects on domestic husbandry farms.

Table 2.2 shows that the technical features of these devices have more advantages compared with common digestion devices: the treating capacity is 2-10 times larger, the production rate of biogas is 1-3 times higher, the reduction rate of COD is 10%-20% higher, and they occupy less area while they are adaptable. Digestion technology and the construction of the devices are the core of the biogas projects. It has been proved that the appearance of these devices and their successful application not only indicate the advancement of the technology for biogas projects in our country, but also provide a solid basis for the further popularization and commercialization of biogas projects on animal farms.

2) Gradual perfection of the technological process

Table 2.2 Features of some common digestion devices

	Normal digester	Reactor for upper flow sludge bed (UASB)	Anaerobic filter (AF)	Reactor for anaerobic contact
Basic operating principle				
Maximum loading (COD kg/m^3/d)	2—3	10—20	5—15	4—12
COD reduction rate under maximum loading (COD mg/m^3/d)	70—90	90	90	80—90
Minimum density for influent (COD mg/L)	5,000	1,000—1,500	1,000	3,000
Volumetric gas output Normal temperature (m^3/m^3/d) Mid-temperature (m^3/m^3/d)	 >0.3 0.6-0.8	 0.6-0.8 1.0-2.0	 — —	 >0.3 ~0.7
Power consumption	Common	Small	Small	Common
Operation & control	Comparatively easy	Comparatively difficult	Easy	Comparatively easy
Blockage	None	None	Possible	None
Land occupied	Comparatively large	Comparatively small	Comparatively small	Comparatively large
Stand striking loading	Comparatively low	Comparatively high	Common	High

Source: "Collection of the theses at the national exchange meeting of experiences from large and medium scale biogas projects." Compiled jointly by Department of Resources of National Economy and Trade Commission and the Department of Environment and Energy, Ministry of Agriculture.

"Technical choice for rural energy." Compiled by China Leading Group Office of the comprehensive construction projects of rural energy.

With the development of the research on the technology for biogas projects and its extension and application, in recent years a comparatively perfect set of technological process has been abstracted. It includes the pretreatment of various raw materials, choice of technical parameters for digestion, after-treatment of the leftover, and the purification, measurement, storage, and use of biogas. Figure 2.1 is the flow chart of the process. In spite of the different requirements and objects for different biogas projects and the different materials for the digestion, which makes some difference in the process, the process in Figure 2.1 principally shows the truth and the general trend of biogas projects on animal farms today in China.

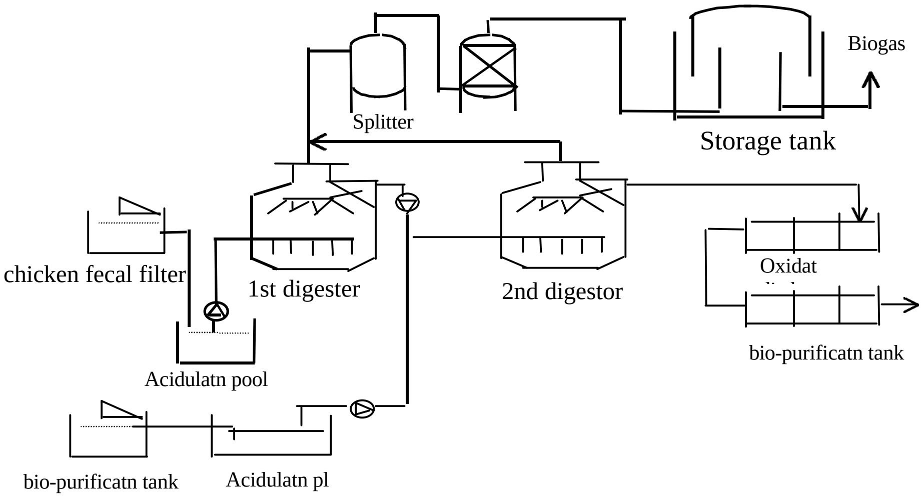


Fig. 2.1 Schech flow chart of anaerobic fermentation

The process has the following important improvements compared to the early one:

- Different pretreatment is employed in light of different materials for digestion. For example, pre-elimination of hair, weed, and grit is performed with animal excrement. In some projects, even acidulation and desulfurization are employed for the pretreatment of the excrement. It has the advantage of preventing choke in the pipes, improving the use of war materials, and raising the rate of biogas production.
- Recycling facilities for the digested residue and three-phase separator are designed, which is helpful for the back-flow of the digestive bacteria and thus ensures a long, normal, highly efficient, and steady production of biogas.
- In some biogas production, the integrated anaerobic-aerobic technology is adopted. It can help improve the quality of the draining water to the drainage standard, but also produces a certain amount of biogas.

- Devices for comprehensive use of the materials for digestion and the leftovers are designed. In some projects, back-flow separation of raw materials is used before and after digestion. Though separation before digestion is different in purpose from the separation after digestion, the former serves the purpose of the harness of pollution and the improvement of environment while the latter is suitable for the purpose of energy production, their roles in the improvement of economic feasibility of biogas projects are just the same.
- Measures for slurry heating and heat preservation are taken.

3) Great improvement of the counterpart equipment

With the perfection of the technological process of digestion, the counterpart equipment has been greatly improved. The improvement can be seen in the following:

- First, a solid and liquid separator is widely used. In recent years, researchers have come up with or chosen some separation devices in accordance with the properties of biogas projects to meet the need for separation machines of comprehensive utilization, digestion technology, and after-treatment technology. For instance, vibration sieve, slope sieve, revolving sieve, and set bed filter have been researched for the separation of animal excrement. The dehydration rate is generally 10%-40%, which can basically meet the technical requirements and the requirements of comprehensive utilization.
- Second, the slurry conveyance devices are based on the homemade ones. Several types of conveyance devices for animal excrement have been successfully researched in light of the characteristics of the diversity in types and the different physiochemical properties of the materials for biogas digestion. Among these devices the efficiency of the homemade 75YE-10 pumps reaches 65% or so, and they provide better performance than those of the same type from abroad.
- Third, further development of the equipment for the purification, storage, conveyance and use of biogas has been made. Some feasible desulfurization technologies have been worked out and desulfurization has reached the standard for the H_2S content in city gas. A steel wet tank is widely employed to store biogas. Besides Rootz blower, air compressor, and nitrogen-hydrogen compressor, which are used convey biogas, special compressors for biogas have been invented as pressure-raising devices. Material for the construction of conveyance pipe has been diversified. In some projects, plastics and casts have taken the place of steel. And at the same time, new advancement has been

realized in the research on the equipment for the use of biogas such as gas furnace, large stove, and biogas electricity generating unit.

4) A major change has taken place in the equipment and materials for the construction

At present, reinforced concrete is commonly used to construct large- and medium-scale biogas projects. The construction period lasts a long time and much area is occupied and the quality is difficult to be guaranteed, which leads to the unqualified construction of some projects and thus the projects fail in operation. In recent years, Hangzhou Energy and Environment Technology Co. cooperated with Lip of Germany. By using their special equipment, they employed the Lip's two-edge folding, edge-biting technology to make Lip tank or jar of 100-5000m^3 from compound steel plate 2-4mm thick. The net weight of the tank is only 10% of that of the reinforced concrete. Compared with the ordinary tank made from steel plate, it saves 30% steel. The construction period is only half of the concrete tank of the same scale. The cost for construction is more than 15% lower. Still this kind of tanks are corrosion-resisting, need no maintenance and thus have a long life.

5) The basic characteristics of the materials for digestion have been made clear

The prerequisite for a proper choice of technology and devices for the digestion is to make known and thus make better use of the basic physiochemical characteristics of the raw materials for digestion. At present the raw materials for the biogas projects on animal farms in our country are mainly excrement of pigs, cattle and chickens. After several years' research and practice, the composition of the elements and the gas production capacity have been made known. Table 2.3 shows the basic properties of the above mentioned raw materials for digestion.

Though much encouraging progress has been made in the technological design, comprehensive use and project management of the medium-scale biogas projects in China, still there is something left to be desired with a view toward its commercialization.

a) The technical equipment has not reached the standard for industrialization and commercialization. There are still quality problems in some critical devices such as solid-liquid separating devices, controlling system and desulfurizing system;

Table 2.3 Common properties of sewage from domestic husbandry farms

Index	Pig farm	Chicken farm	Cattle farm
Humidity (°C)	Same as the washing water	Same as the washing water	Same as the washing water
PH	7	6.5-7.5	7.0-8.2
COD(mg/L)	10,000-15,000	25,000-80,000	25,000-80,000
BOD(mg/L)	6,000-9,000		-
SS(mg/L)	8,000-12,000		-
TVS%		2-8	14.4-22.0
VS%		60-80	78-82.0
NH-N(mg/L)	130-330	1,500-6,000	-
TN(mg/L)	400-600		-
Theoretical biogas production rate(m^3/kg solid mass)			
Solid mass = 20%	0.3	0.3	0.3
Solid mass = 25%	0.4	0.4	0.4
Solid mass = 28%	0.45	0.45	0.45

Source：Prof. Xiong Chengyong

b) The technical securing system is imperfect, and relevant technical standard and norms are needed;
c) The problem of draining according to the standard has not been thoroughly solved;
d) Further promotion of the automation level needs to be realized.

2.2 Economic, Environmental and Social Assessment of Biogas Projects

2.2.1 Economic feasibility of biogas project

Though 460 large- and medium-scale biogas projects have been built since the 1980s, none is totally commercialized with a view toward commercialization. These projects are basically for scientific research, trial demonstration, or welfare, and they lack the design and operation data that meet the requirements of commercialization, including the analysis and assessment of the feasibility of the projects in their draft period. That is to say, there are no direct documents and data that reflect the commercial economic ability. For this reason, the biogas project on the Xizhi breeding farm of Hangzhou is taken as an example in the following. Initial analysis is performed in the way of the cost and benefit to show its economic feasibility and its ability to compete in the market and to reimburse the loans.

The farm is the breeding base initiated by the Xizi Elevator Group, and its annual output is 100,000 pigs with 10,000 as a scale for its first period. First-rate breeding technology and equipment are used for the pig farm with a feed processing plant, a slaughterhouse, a soft-shelled turtle breeding farm, fish farm, environment-protecting vegetable garden and orchard as its counterpart construction. To solve the problem of environment pollution of the excrement and find a new energy resource, a large biogas comprehensive project was constructed on the farm in 1996 which employed the most commonly used technological process in the country and organically integrated the recycling of the resources, exploitation of energy resources, environment protection and improvement of ecological environment. It created the conditions for a substantial solution to the problems such as energy, resource and environment. The technological process of the project is as follows:

The principal equipment and construction includes: 2.4135 million as the estimated investment for the project with 2.8145 million as its total interest investment in the construction period, of which 0.486 million is for the construction of the project.

The utilization of biogas: The average daily biogas production of the project is $500m^3$, of which $30m^3$ is used by the canteen for cooking and the rest is used to generate electricity (50 kW). The daily electricity generation is 850 kWh, which is used to provide the production of the breeding farm, the sewage treating station and the office and public life with electricity.

The utilization of residue: Daily production of residue from the sewage treating station is 100t. The residue is used in the cultivation of environment-protecting vegetables, fish pond and meadow irrigation. If the consumption of residue is not adequate, it is further put to aeration and bio-purification. The content of COD, BOD is 200 mg/L and 60 mg/L respectively, which is up to the standard for drainage. The purified water is later used as washing water for pig sties. Generally about 50 tons of slurry is used as liquid fertilizer for the irrigation of crops and fish-farming; the other 50 tons is used as washing water after being aerated and biologically purified.

The utilization of sludge: 2.8 tons of feed can be produced with the solid-liquid separator every day, which can serve as feed for 250 *mu* fish pond or as vegetable fertilizer.

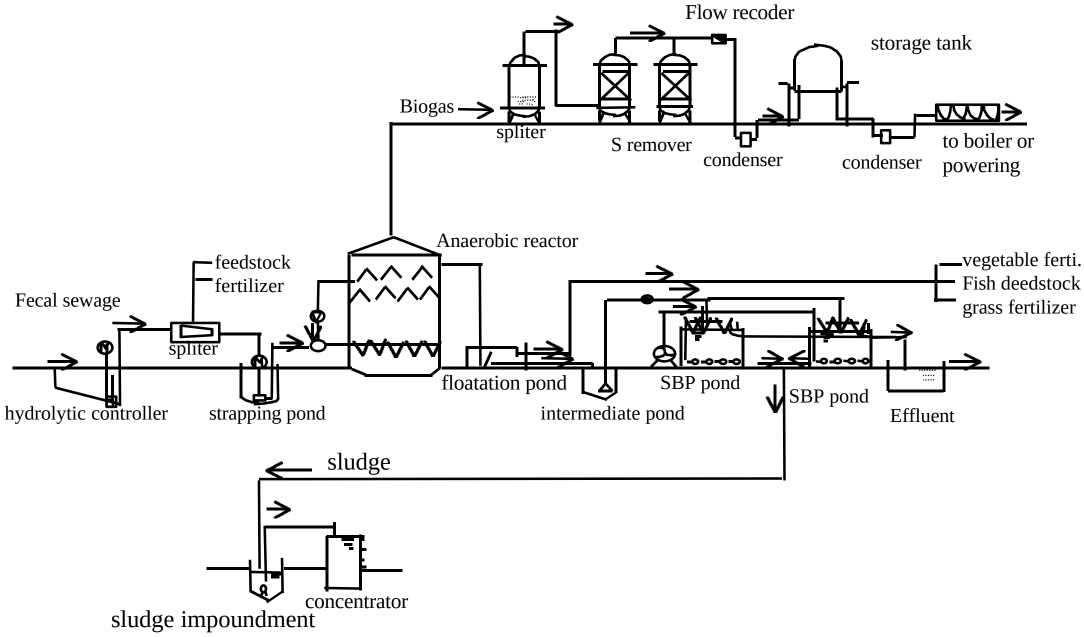


Fig. 2.2 Flow chart of biogas engineering demonstration of Xizi husbandry

The profit of the project totals: 0.655 million *Yuan*/year, which includes:

- Income of 0.205 million *Yuan*/year from biogas (income from electricity generation included);
- Income of 0.33 million *Yuan*/year from other by-products;
- Reduction of the fine of 0.12 million *Yuan* for environment protection.

Table 2.4 Economic assessment of the biogas project on Xizi breeding farm in Hangzhou

	Financial assessment		Economic assessment		Repayment time (financial)
	NPV (10^3Yuan)	IRR(%)	NPV (10^3Yuan)	IRR(%)	
1) Repayment of capital with interest	217.8	11.26	1,097.8	19.04	7 years
2) Repayment of capital with full interest(10%)	-1,267.5	3.34	334	13.88	16 years
3)Repayment of capital with interest(5%)	-292.5	8.43	781.6	16.70	10 years
4) Repayment of capital with interest (5%) + income tax free for 5 yrs	267.2	11.58	781.6	16.70	7 years

The total operation cost for the project is: 21.59 million *Yuan*/year.

Table 2.4 shows the financial assessment and economic assessment of the project. For the parameters for the assessment, refer to Table 2.4.

Table 2.4 shows that:

- The internal economic income rate of the project is high, with the lowest being 13.88%. Moreover, no matter whether the environment effect is taken into account, the interest of the investment remains the same, which proves that the projects of this kind bring about excellent effects for social environment.

- In light of the finance, the projects of this kind do not bring about profitable effects. Even if the reduction of interest is taken into consideration, the net value is still negative and the internal income rate equals or even is less than 10%. Only when the interest of the investment is not taken into account and beneficial supporting policy is granted by the government (as in 4), can it bring about any profit. All this points to the fact that large and medium scale biogas projects on animal farms are still very weak in their ability of market competition and they are not qualified for commercialization.

2.2.2 The social and environmental effects of biogas projects

Elementary biogas projects on animal farms are comprehensive of energy and environment. These projects show the characteristics that in the course of the treatment of the animal excrement efficient energy can be gained, and high quality organic fertilizer, feed and other organic mass can be obtained as well for the promotion of economy. Furthermore, the projects play a role in the purification and protection of the ecological environment. For this reason, it is not enough to just make economic assessment of these projects. Social and environmental assessment should be made about them as well. But there is no mature and publicly accepted assessment for use. There are not only the problems of methodology and index system, but also problems of evaluation and measurement. That the root for a severe lack of assessment of social and environmental effects in practice. In this respect Prof. Gu Shuhua and his colleagues at Tsinghua University take the lead. They take the projects on the Fushan breeding farm in Hangzhou and Xinghuo Farm in Shanghai as their researching object to complete their analysis and assessment of the social and environmental effects. The cost-benefit conversion is characteristic of the research (i.e., the external non-economy is converted to cost and the external economy is converted to the benefit of the projects). Cost and benefit analysis is performed in the research. Maybe it is not in its true name a social and environmental assessment. For the detail of the assessment please refer to Table 2.5.

Table 2.5 Environmental effect of the two projects

	Fushan project	Xinghuo project
Not including processing technology		
NPV (1,000 Yuan)	716.3	491.0
IRR(%)	26.44	13.81
Including processing technology		
NPV(1,000 Yuan)	1,020.0	1,442.5
IRR(%)	31.45	16.90

Notes:

- Data from "Collection of the theses at the national exchange meeting of experiences from large and medium-scale biogas projects." Compiled jointly by Department of Resources of the National Economy and Trade Commission and Department of Environment and Energy of Ministry of Agriculture.
- Fixed cash value of 1990 is used for the analysis.
- The operation life of the biogas projects is assumed to be 15 years.
- The discount rate for the economic assessment is 12%.

The above calculation shows that in light of society and environment the two projects are both desirable. No matter whether the post-treatment is included in the system technology, the internal profit rate and the net current value are ideal. Certainly, if the post-treatment is included in the system design, the economic effect is even better. All this points to the fact that biogas projects contribute to the protection of social environment. Also, this kind of projects provide farmers with high-quality and clean fuel, and make possible the multi-level use of biomass. They should be strongly supported.

2.3 Market Potential of Biogas Projects

At present there are more than 10,000 breeding farms of different sizes in China. But most have no biogas projects. Those with biogas projects constructed amount to less than 5%. So there is still great potential.

According to the investigation and analysis of the research project "Availability of Biomass Energy Resource," among more than 10,000 breeding farms of the country, 500 are large- and medium-scale cow farms with the annual breeding scale of 500 cows. They are mainly located in the west district, especially in the southwest coastal district such as Shangdong, Fujian, Shanghai, Guangdong and Zhejiang. In Beijing, Tianjin, Shanghai and Guangzhou, there are modern cow farms with an annual breeding of more than 1,000 cows. Recently, National Reclamation Department is making plan to build 40-45 modern dairy farms with an annual breeding of more than 1,000 heads in Shanghai. Besides, there are many pig farms and chicken farms. Large- and medium-scale pig farms total more than 2,000 (the annual breeding more than 500 cows). They are mainly located in Beijing, Tianjin, Shanghai, Jiangsu, Shandong and Guangdong. Among them there are 390 in Shanghai, 240 in Beijing and 140 in Tianjin. The distribution of chicken farms is even wider. Except in Hainan, Guizhou, Tibet and Qinghai, there are chicken farms of a certain size in the rest provinces of the country. The size is generally around 0.1-0.3 million chickens, which is nearly 91% of all the large- and medium-scale chicken farms. They provide a sufficient resource for the development of biogas projects.

Moreover, in light of the plan to exploit and use biogas in various districts, the situation is quite encouraging. For example:

The Tianjin municipal government has planned to build large- or medium-scale biogas projects on some selected typical and well-managed cattle, pig and chicken farms in the "Ninth Five-Year Plan," and the gas supply will be concentrated on qualified projects.

The government of Jiling Province plans to build 2-4 large- or medium-scale biogas projects using animal excrement as raw materials in the province during the period of the "Ninth Five-Year Plan."

The government of Hubei Province plans to construct biogas projects on 10 selected animal farms in suburbs of large- or medium-sized cities to cooperate with the development of the "Vegetable Basket Project" during the period of the "Ninth Five-Year Plan." In economically developed and densely populated communities, large- and medium-scale biogas projects will be built to provide the farmers with concentrated supply of biogas for the improvement of their living conditions and energy consumption structure.

大中型沼气工程技术

LARGE-MEDIUM BIOGAS TECHNOLOGY

中国利用沼气工程技术处理畜禽场、酒厂、制药厂、豆制品厂、印染厂及城镇生活污水。图片所示为北京顺义县鲲鹏食品集团肉联厂1200m³沼气工程，运用厌氧与好氧两种处理工艺，日处理污水1500吨，日产沼气400m³。处理后，COD含量<60，BOD含量<20，该工程是由杭州能源环境工程设计所设计。

In China, the large-medium biogas system is used to dispose the wastewater and municipal sewge from husbandry farm, breweries, pharmaceutical factories, bean products mills, printing and dyeing mills, etc.The plctures show the energy-saving type of 1250m ^{3} biogas project, using both anaerobic and aerobic digestions, for treating waste water(1500t/d) from the slaughterhouse, Kunpeng Food Group Corp., and producing biogas 400m³/d in Shunyi county, Beijing. After treatment, COD<60, and BOD <20.This project is designed by Hangzhou Design Insititute of Energy & Environment Engineering.

CHAPTER 3 The Development and Assessment of Biomass Gasification Conversion Technology Fed by Crop Straw

3.1 Status of Development and Technology

3.1.1 Current status of development

As a kind of thermochemical process technique, biomass gasification is able to convert solid biomass materials into gas fuel. Its basic principle is to heat biomass materials so as to break the chains between organic carbon-hydrogen compounds with high molecular weight and decompose them to hydrocarbons with light molecular weight, CO, hydrogen, etc. This kind of conversion will change the form of biomass material into one that can be used more conveniently. It also has a much bigger improvement on the energy conversion efficiency than direct combustion of solid biomass. From Table 3.1, we can see the gasification features of various biomass fuels.

Table 3.1 Gasification features of various fuels

fuel type	fuel features				gasification intensity	gas production	caloric value of gas
	humidity (%)	ash content (%)	size (mm)	caloric value (kJ/m^3)	(kg/m^2/h)	(m^3/kg)	(kJ/m^3)
air-dried wood	25	1.0	80-100	13,598.0	200-250	2.2	4,272.9
wood wastes	23	1.0	sawdust	13,598.0	260	2.3	4,359.7
wheat stalk and rice straw	10	3.5	cracked	14,727.1	180-220	2.3	4,690.3
cowpat	16	6.0	50×50	11,715.2	200-230	2.2	3,907.9
leaves	10	5.0	natural size	13,807.2	200-230	2.0	3,694.5

Source : Biomass energy conversion technology, Northwest University Press (Xi'an: China), 1993.

There are three typical gasification techniques: distillation, rapid pyrolysis, and gasification. The first two are suitable for pyrolysis of wood or wood chips; the last is for gasification of stalks of crops such as corn and cotton. Because of the wide distribution of crop stalk resources, and the rapid increase of requirement for clean, convenient rural energy, an emphasis will be placed on gasification technologies according to the requirement of this research.

Shandong Academy of Sciences developed crop stalks-based biomass gasification and centralized gas-supply system technology. Crop stalks are converted into combustible gas with low caloric value in a down-draft fixed-bed gasifier, then the particulate and tar are removed from the gas, and finally the gas is delivered to households as living fuel for cooking through centralized gas-supply system in a range of natural village unit. After more than 10 years' research, currently there forms a complete set of technologies including crop stalk-based gasifier set, key equipment of centralized gas-supply system, gas pipeline facilities and their construction, household gas stoves, etc. (see Table 3.2). After the demonstration operation in a pilot village, total 14 sets of gasification equipment have been disseminated for use and currently are running in Shandong Province. This kind of gasification system with a scale of 100-200 households is also demonstrated in other areas, such as Beijing.

Table 3.2 Main technoeconomic indices for biomass pyrolysis gasification set

	Dongpan village	Zhangsan village	Tengzhai village	Xunjia village
Setup time	Oct. 1994	April 1996	May 1996	1996
Scale of demonstrated system (households)	98	200	216	186
Type of material	corn stalk	corn stalk	corn stalk	corn stalk
Model of gasifier	XFF-1000	XFF-1000	XFF-2000	XFF-2000
Daily gas-supply (m^3/d)	600	1,200	1,300	1,100
Low caloric value of gas (KJ/m^3)	5,000	5,000	5,000	5,000
Volume of gas tank (m^3)	80	250	250	250
Longest delivery distance (m)	230	350	520	640
Total length of pipeline (m)	2,200		4,250	3,800
Pressure of pipeline (Pa)	2,250	2,800	2,800	2,800
Total investment of project (10^3 Yuan)	156.4	379.6	373.9	3,50.9
Total annual operation expenses (10^3 Yuan)	21.4	43.8	47.5	

Source : The Research Institute of Energy, Shandong Academy of Sciences.

3.1.2 Assessment for technical features and development level of gasification gas-supply system

3.1.2.1 *Technical features*

Gasification set uses a fixed-bed down-draft gasifier. A blower is placed at the downstream of gasifier, which results that the gasifier works at a sub-atmospheric pressure. The top of gasifier is open. Its basic features are illustrated in Table 3.3.

Table 3.3 Basic features of biomass pyrolysis gasification set

Model	XFF-1000	XFF-2000
gas production (m^3/h)	200	500
gasification temperature	over 1,000°C	
gasification efficiency	72-75%	
caloric value of gas (KJ/ m^3)	4,000-5,200	
ingredients for gas		
N_2	49-56%	
CO_2	12-14%	
CO	18-23 %	
H_2	9-12%	
adaptability for feedstock	stalks of corn, sorghum, cotton, soybean, etc. and wood branch, bark, etc.	

Source : The Research Institute of Energy, Shandong Academy of Sciences.

Biomass pyrolysis gasification and centralized gas-supply system is a crop stalk-based biomass energy conversion and cooking gas-supply system in a unit of natural village. Its major equipment is Model XFF-2000 biomass gasification set, which includes crop stalk-based down-draft fixed-bed gasifier, gas cleaning system, and a blower suitable for a distance of 1 km. Its technical features are: using down-draft fixed-bed gasifier, operating at a slightly sub-atmospheric pressure, top-open and consecutive feed. The framework for technical system is illustrated in Fig. 3.1.

3.1.2.2 *Technical assessment for gasification gas-supply system*

- Advancement and Adaptability

  Compared with woody feedstocks, crop stalks have the disadvantages such as low density, high ash content, low carbon ingredient. Thus it has much difficulty in gasification technique and gas clarification than previous gasification technologies. Model XFF-2000 pyrolysis gasification system realized the steady gasification of low-grade biomass materials such as crop stalks. Its main technical indices are equivalent to those of the woody fuel-based types in home or aboard, namely: gasification efficiency of 75%, low caloric value of gas of 5,000 kJ/Nm^3. For gasification of low-grade biomass materials and centralized supply of gas with low caloric value, it is suitable for the current economic and technical levels in China.

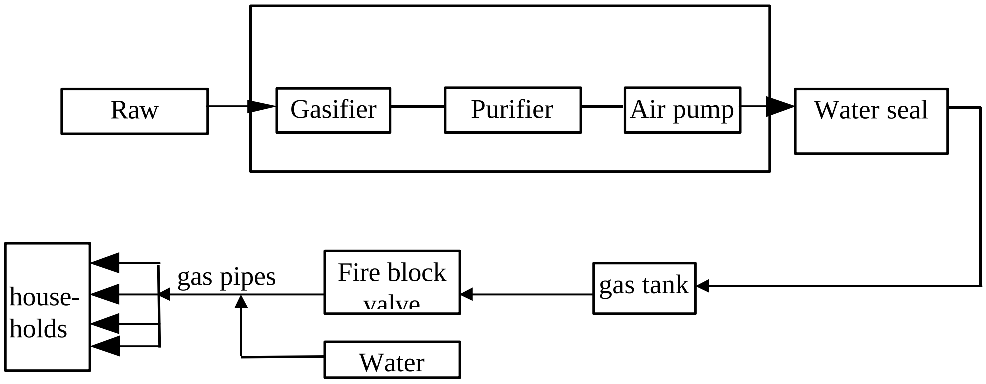


Figure 3.1. Configuration of system

- Integrity and reliability

  The whole system consists of biomass preparation and handling, gasifier, gas cleaning system, ash removal, gas supply and delivery system and related stoves.

  Crop stalks are stored under the situation of natural air-dry. The hay cutter is a general agricultural machine with cheap price and high reliability. The gasifier uses heat-proof cast iron furnace bed, sealed ash bin and machinery ash-removal device. Furnace tank is made up of firebricks, which can withstand a temperature far higher than the furnace temperature. The whole device is composed of steel plates.

  To overcome the problems that crop stalks are soft-quality and of high ash content, and that there is high tar content in the gas, the clarification process of ash-remova→cooling→sedimentation→filtering is adopted. The gas clarifier consists of two-stage whirlwind separator, cooler, gravity settling chamber and filter. At the end of the pipeline, a filter is installed inside the user’s house, to absorb remnant foggy tar using activated charcoal as filtering material.

  The gasification remainder include carbonaceous ash-dust (accounting for 10% of feedstock) and tar (accounting for 5% of feedstock). Currently no effective disposal technique is used.

  Gas supply and delivery system is composed of gas storage tank and pipeline networks. The main parameters for gas storage tank are shown in Table 3.4.

Table 3.4 Main parameters for gas storage tanks with different volume

Volume (m^3)	Diameter (m)	Height (m)	Designed pressure (Pa)	Steel consumption (t)
80	5.8	7.6	4,000	7.32
150	7.4	9.5	4,000	12.6
250	8.9	10.1	4,000	16.7
400	11.3	12.6	4,000	29.8
500	12.5	13.0	4,000	33.6

Source : The Research Institute of Energy, Shandong Academy of Sciences, Technical report on crop stalks-based gasification and centralized gas-supply demonstration project.

3.2 Economic and Environmental Assessment of Straw Gas Supply System

3.2.1 Economic feasibility of gasification system

In the following, taking Model XFF-2000 gasifier gas-supply system in Tengzhai village, Huantai County, Shandong Province as an example, analysis about economic features is carried out for crop stalks-based pyrolysis gasification gas-supply system. In Tengzhai village, there are total farmland of 1200 *mu*, among which 1,100 *mu* is for wheat and corn per year. Most of wheat stalk is directly returned to farmland. The system is the second crop stalks-based gasification system built in Huantai County.

Table 3.5 Construction cost of Model XFF-2000 gasifier and gas-supply system in Tengzhai village (1000 *Yuan*, 1995 prices)

Index	Financial	Economic
Model XFF-2000 gasifier set	75*	90
Hay cutter	0.98	0.98
Gas tank	105	105
Civil engineering of gasification station	63.54	63.54
Installation of equipment	6.5	6.5
Pipeline equipment	76.2	76.2
Household equipment	46.44	46.44
Total	373.66	388.66

Note: * Currently a subsidy of 15,000 *Yuan* is given to village-level crop stalks-based gasification set.

Table 3.6 Operation & Maintenance cost of Model XFF-2000 gasification gas-supply system in Tengzhai village (1000 *Yuan*, 1995 prices)

Index	Financial	Economic
Feedstock(crop stalks)	1	21
Electricity fee	8.76	8.76
Labor payment	8	8
Maintenance expenses for equipment	2.5	2.5
Total	20.26	40.26

The results of cost-benefit analysis show that at a discount rate of 12% and without taking inflation into consideration, its financial internal rate of return (IRR) is 6.0%. Therefore, it is unsuitable for commercial operation of gasification station. Its economic internal rate of return (EIRR) is only 14.4%, which also shows that this kind of equipment needs to improve its economics.

3.2.2 Environmental impact assessment for gasification gas-supply system

Using biogasification centralized gas-supply technologies, it is possible to set up a full set of energy system based on rich agricultural and forestry stalks resources, and to transform the old energy production and consumption mode. It will reduce centralized emissions from burning plenty of crop stalks in harvest season, which cause atmospheric pollution. And it will replace commercial energy so as also to alleviate atmospheric pollution of fossil fuel consumption. If counted by a substitution of 0.17 kgce per m^3 gas, it will substitute 372 kgce for per household with annual gas consumption of 2,190 m^3. Thus, for 200 household gas users, it will reduce coal consumption of about 75 TCE per year. If counted by a substitution of 0.7 t coal per ton crop stalks, it will reduce emissions of CO_2, SO_2 and smoke dust by 14,000 t, 140 t and 100 t, respectively.

In addition, using the gasification technologies, it will bring obvious changes for the environment and the appearance of the rural village, and be beneficial for cooking, alleviating women's labor and saving time.

3.3 Barriers and Prospects for the Development of Gasification Gas-supply System

3.3.1 Possibility of technical improvement

Because it is still in the stage of development and research, many problems need to be solved:

- Gas contains too much CO content to reach the criteria for living gas;
- Gas clarification and the disposal of tar need to be improved;
- Gasification set needs longer operation time for checking and testing its functions, and the reliability and lifetime are also needed to be determined;
- The quality standard and construction criterion have not been formed, so it is difficult for gasification technology to reach engineering stage.

3.3.2 Resource and market potentials

In 1995, total agricultural and forestry energy for living, reached 317.20 million TCE, among which firewood and stalk consumption was 221.40 million TCE while coal was 77.40 million TCE. If 1% of stalk and firewood are replaced by biomass gas by 2010, it will need to build 30,000 gas-supply system with a certain scale, for example 200 households. Thus, it shows a great potential for the development of gasification.

3.3.3 Development prospects

- Because of the financial unfeasibility of biomass pyrolysis gasification system, which is building and operating in rural areas, it is still unsuitable to make commercial application and dissemination for the gasification station in current stage.
- From the results of economic assessment, the system has much better social effects. If it is possible to adjust the current price of gas and get some preferential policies from the state, it will have a brighter commercialization prospect.
- Since the technology is suitable for the current living features of rural households in China, that is living in very wide and scattered areas, and it is also one way to cleanly utilize large amount of agricultural crop residues and stalks, it is feasible to push toward commercialization gradually from the beginning of pilot demonstration projects.

3.4 Analysis for Gasification Power Generation

3.4.1. Necessity for gasification power generation

It is a kind of mature technology in a developed country, for example in the United States, to use producer gas generated by biomass gasification to generate electricity. Currently, the total installed capacity of biogasification generation is up to 9,000 MW, and single unit has a capacity of 10-25 MW.

Leper electricity company of Finland has built a generation station of waste wood-based gasification in Sweden, which can provide heat of 65 MW. The Energy Center of Sweden, using loans from the World Bank, set up a sugarcane residues-fueled generation station with an installed capacity of 20-30 MW in Brazil. In the station, advanced technologies such as biomass gasification and combined cycling generation are adopted.

Energy shortage, especially electricity, is always not completely solved in China. Even if in the coastal areas in the southeast with advanced economy, other electricity sources such as nuclear, natural gas, and imported coal power are adopted to solve the problem, the requirement to digest or dispose crop residues without public contamination is still not be met. For the areas such as timberland in mountains with rich woody resources, it is an effective way to build a small generation station to dispose forestry wastes. For the remote areas without power, especially beyond the reach of power grids, it is also a major technical choice to solve power shortage by utilizing the local biomass resources. Thus, there is a certain market potential for generation using agricultural residues. From the beginning of eighties, rice husks power generation had been applied in Southern China. Rice husks mainly come from the state-owned food process industries in the major provinces of rice production. According to the scale of rice mills in China, a single generation set has an installed capacity of about 160kW. Currently, there are total 92 sets of generators running in China. Some were also exported to other countries. A rice husk-fueled steam thermal generation station with an installed capacity of 1,500 kW has been built in Yueyang, Hunan Province. Based on the current situations, however, it is still in the stage of research for crop stalk-based biomass gasification generation.

3.4.2 Adaptability of gasification generation technology

Currently, there are several technological means suitable for biomass gasification generation. A posteriori, it has the following types: simple mobile gasification generation set, mid-scale gasification generation system, combined cycling gasification generation system (see Table 3.7) and village-level small gasification generation system equipped with a Stirling engine. The table shows that for the three means, their feedstock types are woody wastes with high caloric value. For soft woody resources such as crop stalks with low caloric value and high tar

Table 3.7 Technical schemes suitable for biomass gasification generation

Type	Major technical indices	Operation mode	Adaptability and area	Advantages	Problems
Simple mobile gasification generation set	power: 2.5-30 kW generation efficiency: 11-14% generation parameters: normal criteria	single or double engine, change filter material every tens of hours	for lightening in village, farm and tree farm or driving small motor	compact equipment, easy operation, high adaptability	low efficiency, unsuitable for consecutive operation, big unit investment
Mid-scale gasification generation system	power: 60-2,000 kW system efficiency: 15-18% generation parameters: normal criteria	fluidized-bed or cycling fluidized-bed, consecutive operation	for lightening or small industries in village, farm and tree farm, supply captive power for food or wood process factories	lower tar content, no use of filter material	much initial investment for combined gas clarification system
Large-scale combined cycling gasification generation system	output power: 5,000-50,000 kW system efficiency: 35-45%	long-term, consecutive operation	supply electricity for industrial	big disposal capacity, high auto-mation degree, and high system efficiency	too big initial investment for gasification and clarification

Source : "Application Analysis for Agricultural Biomass Gasification Generation Technologies," Guangzhou Institute of Energy Conversion.

content, they are not suitable. In addition, the latter two types of equipment need plenty of crop stalks as feedstock for its bigger installed capacity, so it also cannot satisfy the situation that crop stalks distribute very widely and scatteringly in rural areas of China.

Because there are plenty of scattering crop stalks in rural areas in China, it is much better to choose a small scattering power station with an installed capacity of hundreds of kW and using biomass gasification-gas engine-generator technology, to meet the requirement of about 200 households in a natural village. However, current technical barriers lie in low efficiency for gas-fueled engine (generally about 15-20%) and low power (40-50% lower than the oil-fueled), so it results in economic unfeasibility for gas generation. A Stirling engine is employed to solve this problem, which is a kind of sealed cycling piston-type engine heated by outside energy. It has the following distinguishing merits:

- Its combustor lies outside the engine, and does not touch the transmit components such as piston of cylinder. Heat is transmitted into the cylinder through the wall of the heater, so it is able to adapt many kinds of fuels such as combustible gas, oil and coal, even other heat sources like solar energy.
- Its efficiency is up to 40%, much higher than that of an internal-combustion engine, e.g. 20%. Combined with generator, the efficiency of whole set is about 30%, equivalent to average level of fossil-fired power generation in China.
- It has very low noise, being only about 10-20% of the internal combustion engine with the same capacity.

It is of low emission and pollution. Emissions of NO_x and CO are far lower than general internal combustion engine.

The STM company of the United States, owned by GM company, is a specialized one to develop Stirling engine technology. It has the license of Philip company's Stirling engine technology and has mastered advanced technologies on the civil field. It developed the STM4-120 engine, appraised as the most advanced Stirling engine in the world by the U.S. Department of Energy (DOE). Combined with China's mature biogas technology and biomass pyrolysis gasification technology, it can be constituted into village-level biomass gasification generation system with a small capacity (50 kW). It is, however, of high cost for the current limited production scale.

3.4.3 Analysis for scale and economic features of gasification generation

According to the main technoeconomic indices of the mid-scale cycling fluidized-bed gasification generation system with an installed capacity of 1,500 kW (see Table 3.8), the caloric value of its feedstock is 12,546 kJ/kg, so there are still problems for using crop stalks with a caloric value of about 5,000 kJ/kg. Furthermore, it will need too much raw materials to suit for villages and towns.

For the technology that combined gasifier with Stirling engine, it is not mature for carrying out the technical research on the field in China because of the high cost of a Stirling engine. How to assess its economics will depend on the enforcement for the cooperative research and demonstrative dissemination on the fields between China and the United States.

Table 3.8 Main techno-economic indices for mid-scale cycling gasification generation system

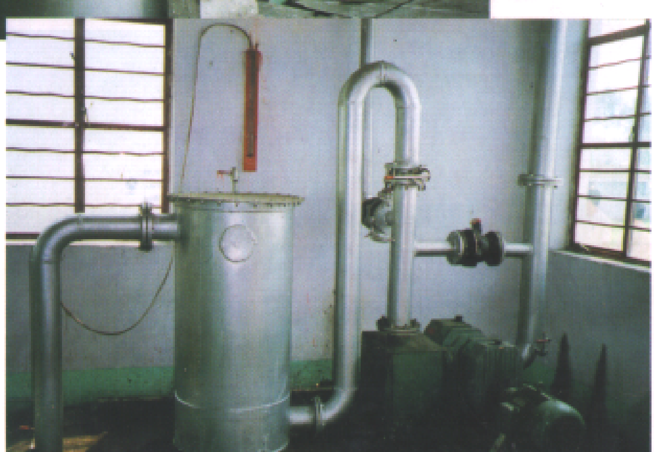
Scale (kW)	1,500
System efficiency (%)	17.0
Operation availability (%)	70.0
Annual generation (10^3 kWh)	9,070
System life time (year)	10
Fuel consumption (agricultural wastes, t/yr)	15,309
Caloric value of fuel (KJ/kg)	12,546
Fuel price (Yuan/t)	110
Total investment for gasification and purification (1,000 *Yuan*)	2,800 1,000
Annual depreciation of equipment (1,000 *Yuan*)	383.0
Labor expenses (1,000 *Yuan*/yr)	90.0
Annual transport and other expenses(1,000 *Yuan*)	406.2
Price of grid power (*Yuan*/kWh)	0.35
Annual benefit of project (1,000 *Yuan*)	3,174.5
Discount rate (%)	10

Note: Crop stalks needs to be collected in a range with a diameter of 4 km, and the transport expense is 5 *Yuan*/t/km.

农作物秸秆气化供气系统

GAS SUPPLY SYSTEM OF BIOMASS GASIFICATION FED BY CROP STRAW

该类气化系统利用农作物秸秆（玉米秸、棉柴、麦秆等）为原料，将其转换为可燃气体，用于农村炊事、烘烤、加热。气化率为72%～75%，燃气热值为4000～5200kJ/m^3。主要是利用中国丰富的秸秆资源，为农村地区提供清洁的能源和解决由于焚烧作物秸秆对当地带来的环境、交通和社会问题。图片所示为山东省兖州小马青村，气化机组为XFF-2000型，供气户数为289户。该装置由山东省科学院能源研究所设计。



The biomass gasification system is a system which converts such biomass as corn stalk, cotton stalk and wheat straw to combustible gas for cooking, drying, and heating,with the gasification efficiency of 72-75%, gas heat value of 4000-5200kJ/m^3. The system is developed for rural areas in China, to use the huge biomass resource to provide clean energy,and solve the environmental, communication, and social problems caused by directly burning the crop straws. The pictures show a Model XFF-2000 system for supplying 289 households in Xiaomaqing village, Yanzhou,Shandong Province, designed by Energy Research Institute, Shandong Academy of Science.

CHAPTER 4 Development Situation and Assessment of Municipal Refuse Landfill Biogas-Power-Generation Technology

4.1 Status of Technology Development

4.1.1. Technology description

Landfills are different from natural dumps. The natural dump is to dump refuse in wasteland and ditch without any cover or scientific disposal. Natural dump was applied in many cities in China before the 1980s. The disadvantage of this technology is obvious. Due to the air storage of refuse, a lot of bad smell gas and butterflies, mosquitoes and mice will ruin the ecological system near the dump cite and harm public health. Meanwhile, percolating water, heavy metal and others harmful materials decomposed by microorganisms from refuse will seep to underground and pollute water resources.

Landfill is developed to solve these problems with the aim of preventing the secondary pollution. The advantages of landfill are: (1) pollution of surface water and underground water can be prevented by the seepage control in advance; and (2) inflammable and explosive gas emitted from refuse can be collected by pipeline and will be used for power generation or chemical raw materials. After conveyed to the landfill plant, refuse is spread as a layer of 30-50 cm thick, then compacted, covered by a soil layer of 20-30 cm thick. The refuse layer and soil layer together constitute a landfill unit. The refuse conveyed to the landfill plant every day will be compacted to be a landfill unit. A landfill layer consists of a series of landfill units. A whole landfill plant is consisted of one or more landfill layers. Whenever the landfill thickness reaches the designed height, a soil layer of 90-120 cm will cover the top layer and be compacted, then a whole plant will be completed.

Landfill is just one of the municipal refuse disposal technologies. Incineration, high temperature fertilization, etc., have their own advantages and can be applied in different situations.

Landfills are popular in many countries because they are simple to operate, low cost, and suitable for various kinds of refuse and energy recovery. At present, 4,817 landfill plants have been built all over the world: 2,247 are in America and 175 are in Europe. Worldwide, 5.142 billion cubic meters of landfill biogas is collected annually, equal to 2.4 million tons of crude oil.

Disadvantages of landfills are: (1) large land requirement, as time goes by, it will be more and more difficult to find a more suitable site; and (2) the secondary pollution. Experiences have demonstrated that percolate and gas of refuse will harm the surrounding environment if they are not disposed properly.

4.1.2 Improvement of technology

To solve the secondary pollution problem and save land resources, some technical measures have been taken and received good results as follows:

(1) Raise the height of landfill plant will be useful to save land and decompose refuse to produce biogas.
(2) New materials and technologies have been adopted to strengthen the impervious barrier, sewage disposal system is also installed to prevent the pollution to water resource.
(3) Refuse leaching solution and biogas collecting pipeline are built to increase the biogas collecting efficiency. Now the main uses of biogas are fuel, domestic use after being cleaned, and power generation. The final use is determined by the situation of the region where the landfill plant is located. The percentage of biogas used for power generation is 80% in America and 50% in Europe.
(4) Compacting the refuse to preventing air from entering the refuse, avoid the aerobic reaction.

In general, along with the improvement of landfill technology and the more and more abundant operating experience, landfill technology is tending to reach perfection, and has solved the following technical problems successfully:

- Projection of landfill plant biogas production
- Preventing air from entering refuse
- Seepage control and sewage disposal
- Shaft drilling and equipment manufacturing
- Horizontal pipeline building and condensed water removing
- Biogas collection and pressurization
- Biogas power generation and equipment manufacturing
- Dust elimination of power generator
- H_2S control

4.1.3 Status of municipal waste disposal technologies in China

Now in China, only a few units have taken part in this research of municipal refuse disposal technology. For example, Chengdu Creature Institute of Chinese Academy of Science completed the research of biogas production from refuse anaerobic zymosis during 1985-1986, research of municipal organic refuse systematic disposal during 1987-1990, and the pilot-scale test of $160m^3$ had also completed.

In the aspect of project construction and demonstration, there is not much experience available. By now, the completed harmless landfill projects are:

- Qingshan municipal refuse harmless landfill plant in Baotou
- Asuwei refuse harmless landfill plant in Beijing
- Laogang refuse harmless landfill plant in Shanghai
- Tianziling refuse harmless landfill plant in Hangzhou
- Datianshan refuse harmless landfill plant in Shenzhen
- Zaikeng refuse harmless landfill plant in Zhongshan, Guangdong
- Xiaping refuse harmless landfill plant in Shenzhen
- MengYuan refuse harmless landfill plant in Nanchang

Power generation has played a more and more important role in the utilization of gas of landfill plant. Now the main equipment consists of the internal combustion engine and the turbine. Otto engine and Diest engine are the commonly used engine of internal combustion engine. However, gasifiers, which can provide proper mixed gas to combustor, should be added to the engine before they are used in landfill plant.

Since the octane number of the fuel for Otto engine is less than that of landfill gas, so the bulk of combustor should be reduced to let the engine reach designed output. But the octane number of the fuel for Dised engine is higher than that of landfill gas, so the engine can reach designed output by enlarging the bulk of combustor and adding an automatic spark instrument. Both the two kinds of engines have their own market. Gas turbine and steam turbine are all applied in some plants, the advantage of gas turbine is its large output per unit weight, about 70-140 kW/ton, much higher than 27 kW/ton of internal combustion engine and 10 kW/ton of steam turbine. The statistical data show that internal combustion engine is applied in 61 landfill plants in America, turbine is used in 24 plants, the total installed capacity is 344MW. In Europe, there are 50 sets of internal combustion engines on operation, the capacity of big unit ranges from 400 to 2,000 kW. Some small internal combustion engines can be contained and conveyed from one landfill plant to another. Which kind of engine will be applied is determined by the production of biogas. Internal combustion engine is suitable for the capacity from 1,000 to 3,000 kW, if the installed capacity needs to be more than 3,000 kW, turbine is the better choice with higher efficiency. At present, the efficiency of landfill biogas power generation is about 1.68-2 kWh/m^3 in China.

Some development research has been taken in China, mainly focus on internal combustion engine, just some simple improvement of gasoline or diesel engine; the manufacturing capacity of biogas engine has not been built.

Altogether, from the point of view of technology, landfill technology has been well developed and commercialized in foreign countries. Although some landfill plants have been operated successfully in China, the landfill technology is still at demonstration level with less experience, developing technology.

4.2 Economic Feasibility Analysis of Municipal Waste Power Generation

4.2.1 Economic feasibility

The economic feasibility of refuse power generation project concerns the whole procedure of the biogas production from refuse. Firstly, the production rate, production and collection rate is determined by the scale and technical design of the landfill plant. Landfill plant with the scale of over 1 million tons of refuse, 10 ha of area or 10 meters of landfill has higher rate of return on investment of biogas power generation. Meanwhile, the biogas collection system of a landfill plant is very important too. If the biogas collecting pipeline and refuse leaching solution system are built before the plant started, the production rate and collecting rate of biogas will be higher than 75%. If the power generation project is to be built in a complete landfill plant, the biogas has to be collected by pothole, so the production rate and collecting rate cannot be very high.

Second, electricity price is also a very important factor.

In the aspect of policy, the economic feasibility of biogas power generation project will be improved greatly with beneficial tariff and credit and implementation of environment protection laws.

The Tianziling refuse power generation project in Hangzhou is a pilot project. Its economic feasibility and capacity of reimbursement are shown blow. Tianziling landfill plant locates in Hangzhou, its square measure is 160,000m^2, designed capacity 6,000,000m^3, 1.4 million ton of refuse had been filled by the end of 1995. The whole project is designed by Canada, biogas is collected by pothole, and the power generator is gas turbine. The installed capacity is 1,520kW, annual operation time is 95% of total time. The annual power output is 12.7GWh. The total investment is 2.5 million USD. Analysis from the Canada company shows that the rate of return on investment of this project is 14.8%, which means this project is economic feasible under the following conditions:

- Service period: 15 years
- Rate of inflation on operation and management cost: 5% annually
- Rate of inflation on labor: 10% annually
- Rate of inflation on electricity price: 5% annually
- Electricity price:
  i) 0.63 *Yuan*/kWh in the 14 peak hours
  ii) 0.17 *Yuan*/kWh in the 10 non-peak hours
  iii) 0.438 *Yuan*/kWh in average (equals to 0.0538USD/kWh)

4.2.2 Environmental characteristics

Landfill biogas power generation is developed to prevent environment pollution, so the second pollution to environment is also avoided. The regional environmental benefits of the construction and operation of this project are:

1) Avoid the explosion and fire caused by landfill gas.
2) Prevent the pollution to underground water. Sewage disposal system must be installed in standard landfill plant, so the landfill leaching solution won't leak.
3) Helpful to GHG emission reduction. Since the emission reduction of 1 ton CH_4 equals to that of 25 tons CO_2, so the implementation of landfill power generation is very beneficial to the emission redact of GHG such CH_4, etc..
4) Recovery of landfill biogas can reduce the bad smell of gas emissions greatly.
5) Not only the harm to environment from landfill gas, but also the pollution from conventional energy power generation can be reduced by landfill power generation.

4.3 Market Potential Analysis of Landfill Power Generation

4.3.1 Problems and barriers of further development of landfill power Generation

The main problems of landfill power generation market in terms of following aspects are:

(1) ***Resource*** **:** The market potential of landfill power generation is affected by two factors, one of which is the municipal refuse production. As a country with huge population, there are over 300 million urban population in China; the annual municipal refuse production is over 100 million ton. But the rate of refuse collection is quite low as about 40%, most refuse are piled anywhere, so the available refuse is not so much. The other reason is because most refuse are piled everywhere, so it is very common that there are hundreds of landfill plants in a city but most of them have not been planned and designed scientifically. Without bottom cleaning, soil cover layer and horizontal pipeline, the production and collection rate of biogas is low, and the plant is just a large pollution source, which also affect the economic feasibility of power generation with landfill gas.

(2) ***Technology*****:** From the worldwide view, after tens of years, landfill power generation technology has shown its well developed with successfully solving some key technological problems. However, there is a key problem which has not been solved, i.e. biogas production rate is only $0.1m^3/kg$, together with the speed of biogas production, which is far below the theoretical value. This problem will not only be concerned with the competition between conventional energy and refuse in power generation, but affect the economic feasibility and market potential of refuse power generation as well. From the domestic view, the landfill power generation technology has not been well developed or systematized, or even unavailable. The main technologies and equipment of landfill power generation projects, which currently under construction in Beijing (Asuwei), Hangzhou (Tianziling), Guangzhou (Likeng), Shanghai (Laogang) are all introduced from abroad. Nevertheless, it is quite difficult to change such situation recently.

(3) ***Economy*****:** Since China is a developing country with limited economic strength, the investment for municipal refuse disposal mainly focuses on the collection of refuse and construction of landfill plants. The refuse landfill power generation project cannot be commercially developed recent because of the lack of fund. However, this will provide an opportunity for foreign companies to enter the Chinese market.

(4) ***Policy*:** Laws and regulations of solid waste are issued this year, government-owned and private enterprises are encouraged to take part in the recovery and utilization of waste. Thus, lots of wastes such as metal, paper and glass can be recovered, so the increase of ratio of organic matter in refuse will be helpful to the biogas production in landfill plant. But no laws for the biogas emission from landfill plant is issued, which is unfavorable to the market development. In addition, no favored duty and credit is provided to refuse power generation; for example, electricity sector can't support the refuse power generation so actively as conventional energy power generation, and the electricity price cannot be the favorable price.

(5) ***Social acceptability*:** No one wants to dump refuse in his own garden. More and more municipal refuse is spreading to rural area, in order to avoid pollution and save land resource, the public hope that refuse can be centrally dumped and disposed without any environmental pollution. It has been shown from the practice that scientifically designed refuse landfill biogas project is well received by public for its no secondary pollution, clean production, clean disposal, etc..

4.3.2 Market prospect analysis of municipal waste power generation

(1) Now the rate of refuse harmless disposal is less than 3%. Along with the increase of urban population and living standard, municipal solid waste increases rapidly. According to statistical data, the annual refuse production is over 100 Mt in China, and the organic matter is over 30 Mt and the total production will reach 180 Mt by 2010. Usually, these refuse is openly dumped or simply landfilled; this must be improved for the reason of pollution and public health. The refuse landfill biogas power generation is one of the main solutions to solve this problem.

(2) With the development of a social economy, the urbanization rate will increase gradually in China. By the end of 1994, there were 622 big-medium cities in China, of which 33 cities with population over 1 million, 42 cities with population from 0.5 to 1 million, 173 cities with population from 0.2 to 0.5 million, 375 cities with population less than 0.2 million. If incineration is not suitable for small cities(population less than 0.5 million), landfill technology will be the best technical option.

PART TWO CASE STUDY

CHAPTER 5 Biomass Gasification System for Central Gas Supply
--Economic Evaluation of Gasification System at Tengzhai, Huantai

5.1 The Project's Background Information

5.1.1 Background

Along with the development of agriculture and rural economy, the straw production is also increasing continuously. Because of the more and more consumption of coal and LPG and the popularization of improved stove, straw is surplus in many places; and burning disposal will cause the problems of resource waste, environment pollution and traffic safety. In order to utilize the energy in straw, State Science and Technology Commission and Ministry of Agriculture had started to organized the research of biomass gasification technology during the "Seventh Five-Year Plan". The straw gasification demonstration project in Huantai County, Shandong Province was arranged by MOA during the "Eighth Five-Year Plan".

The first straw gasification system which is developed by Shandong Energy Research Institute was installed successfully in Dongpan village, Huantai County, Shandong Province in October 1994 and was highly evaluated by local people. Tengzhai is the second village which built the gasification system. After being tested for some years, straw gasification technology is developed with stable gas output, system performance and good reflection from users, and has allured great attention from public. More than ten gasification systems had been built in Shandong Province just in the following two years. After approved by Shandong Province government, Shandong Agriculture Bureau started to implement the straw gasification demonstration project along the Jinan-Qingdao highway. The project is getting on all right with 20 completed systems in villages.

5.1.2 The natural and geography situation

Huantai County is in the middle of Shandong Province, located at the north of Lubei Plain, sitting among East Longitude 117°49'-118°00' and North Latitude 36°54'-36°04'. It is belong to temperate monsoon climate zone, the annual average temperature is 12.5°C, and the annual precipitation is 586.4 mm. The total area of Huantai County is 510 km^2, cultivated land area is 478,000 *mu* (34,200 hectares), percentage of forest cover is 15.9%. Tengzhai village lies in the northwest of Huantai County, cultivated land is 1,200 *mu*, it is the second straw gasification system set up after the first one in Dongpan village near the south of Tengzhai village in Huantai County.

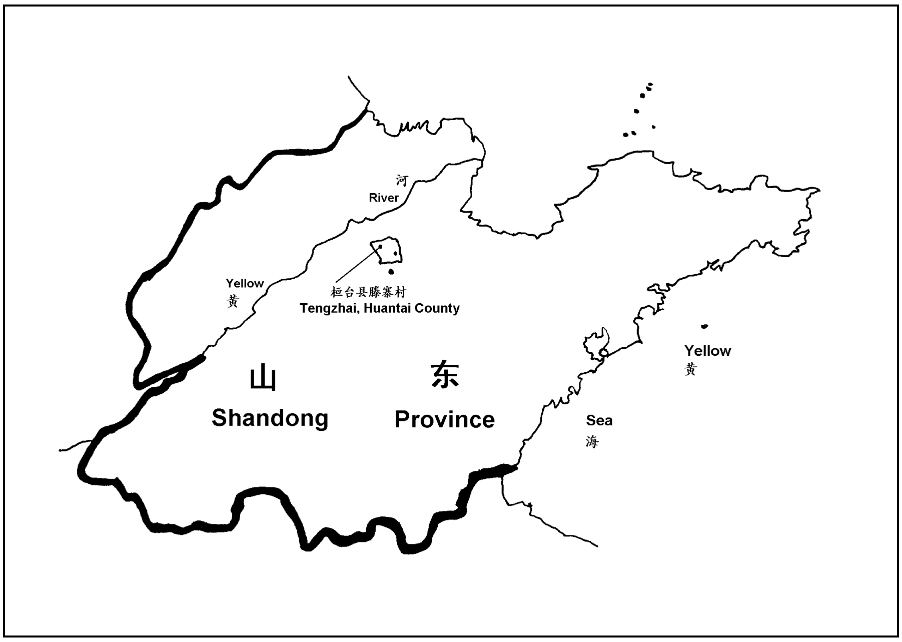


Figure 5.1 Sketch map of Tengzhai village, Huantai County location

5.1.3 Social economic development information and environment situation

In 1995, there were 13 towns, 1 development zone and 343 administrative villages in Huantai County, the total population is 470,000 with 420,000 of agriculture.

Huantai County is one of the commercial grain productive base of nationwide, belongs to the first hundred counties which have the multiple forces in developing. In 1995, the Huantai's GNP is 3.89 billion *Yuan*, and the output values of agriculture and town-and-village enterprises are 1.03 billion *Yuan* and 2.21 billion *Yuan* respectively. The county's financial income is 43.9 million *Yuan* and the annual income of farmer per capita is 2,280 *Yuan*. The total electricity consumption is 0.231 TWh with 0.009 TWh for township daily life and 0.021 TWh for rural. See Table 1.1 for detailed ecological environment information.

Table 5.1 Index of ecological environment of Huantai, 1990-1995

Item	1990	1995
Organic matter content in soil (%)	1.4	1.5
Ratio of forest cover (%)	10.7	15.9
SO_2 emission (ton)	4,572	4,320
Soot emission (ton)	1,094	1,992
Sewage production (1,000 ton)	5,890	2,660
Sewage disposal (1,000 ton)	445.9	763
Ratio of dung disposal (%)	3.3	7

There are 216 households in Tengzhai village, with 800 population. There are farmland of 1,200 *mu*, 7 village-enterprises employing 500 workers, of which 2/3 are local farmers. The total industrial production is 23 million *Yuan* in 1995, meanwhile the total agricultural production is 2.7 million *Yuan*, the annual income per capita of farmers is 2,300 *Yuan*.

The cultivated land of wheat and corn is 1,100 *mu* in Tengzhai every year. Most wheat straw is used as fertilizer directly, and it is still difficult to use corn straw as fertilizer directly. The annual production of corn straw is 1,320 ton. Corn stalk is seriously surplus in Tengzhai village for the reason of few cattle fed and cooking use, most of them is burned at the farm land to no purpose. But in recent years, straw and stalk burning is forbidden by local government, so the straw and stalk disposal becomes a trouble to the farmers. The straw gasification technology just provide a solution to this problem.

5.1.4 The resources and availability of straw and stalks in Huantai County

With smooth plain land, perfect irrigation system and protest forest web of agriculture land, Huantai County is famous for its developed agriculture in North China, especially for its wheat and corn cultivating, which are the main crops in Huantai. In 1995, the cultivated land is 380,000 *mu*, and the total production of grain is 420,000 tons. Thus Huantai County possessing 540,000 tons of straw and stalks in 1995.

In 1995, there are about 10,000 tons of straw and stalks ensilaged and ammoniated for raising livestock, 50,000 tons used as industry material to make artificial slight plank, furfural and paper, 250,000 tons of straw and stalks returned directly as

Table 5.2 Resources of crops straw and stalks in Huantai (1995)

Crops	Production (1,000 ton)	Ratio straw to grain	Coefficient of coal equivalent	total amount (1,000 ton) actual	coal equivalent
Wheat	195	1	0.5	195	97.5
Corn	161	2	0.5	322	161
Cotton	3	3	0.53	9	4.8
Oil crops	6	2	0.5	12	6
Sum				538	269

fertilizer, 60,000 tons for cooking by direct combustion, and the remainder is 80,000 tons.

By average calculation, every administrative village in Huantai possesses 1,568 tons of straw and stalks, and the average collection radius is about 0.7 kilometers and the purchasing price is 0.2 *Yuan*/kg for wheat straw and 0.12 *Yuan*/kg for corn stalk.

5.2 Technological and Economic Characteristics

5.2.1 Technology and system description

The pilot project of Tengzhai village begins to construct in the winter of 1995, and accomplished in May of 1996. Being labeled the model of XFF-2500, the technical features of gasifier are as follows: fixed bed and down sucking gasification reactor, operates under small negative pressure, straw and stalks are added constantly from the upper opening mouth which is opened to the air. After being removed of the dusts and purified through the filters, the fuel gas is conducted to a storage tank by a air pump.

System description: The stalks are cut into small parts and put on the conveyer to be transported into the gasifier, in which the stalks become combustible fuel gas by pyrolysis reaction. The dust and tar containing in the raw gas are removed in purifier. The air pump transports the fuel gas to the storage tank. The gasifier, purifier and air pump compose the gasification unit. The storage tank is used not only to store a certain amount of gas to balance the load's fluctuation, but also to maintain a stable pressure of the fuel gas contributed to the households so as to assure the gas having steady combustion on the household stove. The water seal is used to prevent the gas flowing back to the gasifier after the unit stops running, and the fire block valve is another safety assurance device. The gas left from the fire block valve is contributed to each household by pipeline network which is buried under the earth. In the network, there are several water holders which are used to hold the condensed water in the pipeline.

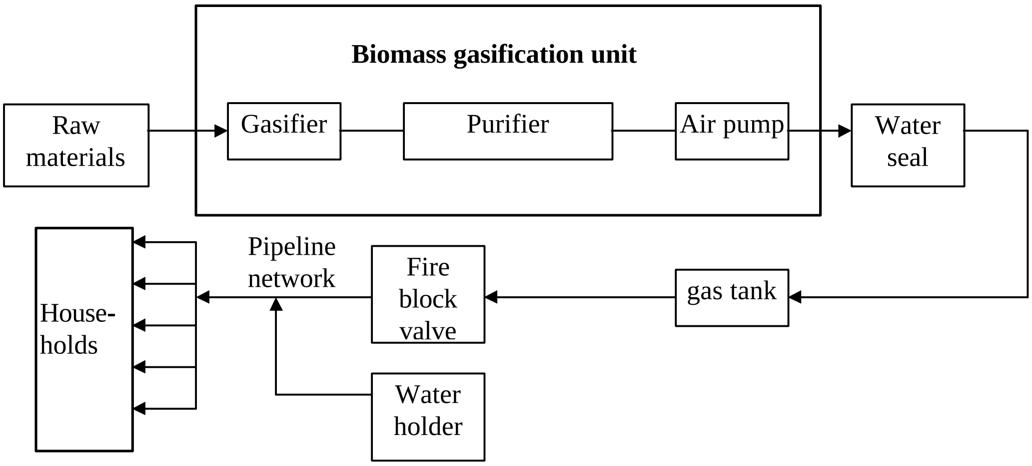


Figure 5.2 Process flow

5..2.2 The Main Technical Indexes

Table 5.3 The main technical indexes of Tengzhai village straw and stalks gasification system

Index	Unit	Data
Total households supplied with the gas	household	216
Straw and stalks consumption	ton/yr	200
Volume of storage tank	m^3	260
Gas supply	m^3/day	1,300
Pipeline pressure	Pa	2,800
Pressure pre stove	Pa	800
Max. distance of supply	m	520
Heat value of the gas	kJ/ m^3	5,200
constants: CO	%	21.4
H_2	%	12.2
CH_4	%	1.9
CO_2	%	13.0
O_2	%	1.6
Efficiency of gasification	%	72-75
General efficiency of energy utilization	%	36.5

5.3 Investment Analysis

5.3.1 The investment

The gasifier unit used at Tengzhai village is provided by Shandong Energy Research Institute, which sold in the market at price of 90,000 *Yuan*, and only as 75,000 *Yuan* to Tengzhai because of the pilot project. The total investment of the project is sum up to 387,900 *Yuan*, and the details are illustrated in Table 5.4. As a pilot project, it got a subsidy of 125,000 *Yuan* from government. Every household has to hand in 300 *Yuan* for using the stalks gas. So the village invested in the project 183,100 *Yuan* eventually.

Table 5.4 The detailed investment of Tengzhai village gasification system

Components	Item	Specification	Quantity	Expense (1000 *Yuan*)
Gas station	sum			266.3
	gasifier	XFF-2000	1	90
	storage tank	$250m^3$	1	105
	hay cutter		1	1
	water pump		1	0.3
	base of the tank			7.3
	land and building			54
	install			6.5
	others			2.2
Pipeline network	sum			76.2
	pipe lines			57
	spare parts			7.7
	water holders			2.3
	labor			9.2
Indoor facilities	sum			45.4
	stove	40 *Yuan*	216	8.64
	gas meter	100*Yuan*	216	21.6
	final filter	30*Yuan*	216	6.48
	tube and spares	40*Yuan*	216	8.64
Total				387.9

5.4 Operating Costs and Benefits

- ***Material*** **:** The raw material used in the gasification system is corn stalks, which only has the collection cost in the viewpoint of the village at present time. The village pays 5 *Yuan* per *mu* for stalks transportation expense. If every household uses the straw gas, 200 tons of stalks are required for 216 households use per year, which is analogous to the stalks of 200 *mu*. Thus, the financial cost at the village scale is 1,000 *Yuan* every year. In view of the market point, the price of corn stalks is not the market price. In 1995, 25% of the corn stalk was burned. The main use of corn stalk is feedstock. So the opportunity cost of corn stalk is 0.06 *Yuan*/kg. Thus the annual economic cost of material is 13,000 *Yuan*.

- ***Power*** **:** The total power consumption of the gasification station is 8 kWh, and the service time is 4 h/d. At present, the electricity price is 0.75 *Yuan*/kWh for agriculture use, 0.90 *Yuan*/kWh for industrial use and 0.45-0.65 *Yuan*/kWh for domestic. The annual electricity cost is 8,800 *Yuan* at the price for agricultural use.

- ***Personnel wages*** **:** Two staffs are required, the total annual wages is 8,000 *Yuan*.

- ***Maintenance cost*** **:** The mechanical equipment such as hay cutter, water pump, air pump and electric motor need to be kept in good condition and repaired or replaced regularly. If all of them are replaced every 3 years, the average annual cost of these facilities is assumed to be 1,500 *Yuan*. As the final filter in the household is required to be checked and replaced every 2 months, and the annual cost of whole village is assumed to 1,000 *Yuan*. Thus the total cost for maintenance is 2,500 *Yuan*.

- ***Sum of the annual operation costs*** **:** 20,300 *Yuan* for financial cost and 32,300 *Yuan* for economic cost. See table 5.5 for details.

Table 5.5 Annual operating cost

Item	Financial(1,000 *Yuan*)	Economic(1,000 *Yuan*)
Raw material	1	13
Power	8.8	8.8
Wage	8	8
Maintain	2.5	2.5
Total	20.3	32.3

5.5 The Benefit Analysis

Table 5.6 Benefits

Item	Financial	Economic
Gas production (1000 m^3)	388.8	388.8
Benefits (1,000 *Yuan*)	38.9	101.1

5.5.1 Financial benefit

The village sells the gas at 0.10 *Yuan*/m^3 to maintain the operation of the gas station. As 150 cubic meters are required for 1 month each household, the whole village of 216 households will use 388,800 m^3 and the gas station can get an income up to 38,900 *Yuan* every year.

5.5.2 Economic benefit

The LPG consumption will be one bottle/month per household and the price is 40 *Yuan*/bottle (12 kg). The effects of using straw gas and LPG are identical despite the quantity, and using straw gas may eliminate the purchasing labor and expense. Therefore, it can be calculated that the alternative price of straw gas is 0.26 *Yuan*/m^3 based on the consumption of 150m^3/month per household. If calculated on the basis of heat value and efficiency, the alternative price of straw gas will be:

$$(5\text{MJ/m}^3 \times 0.50)/(46\text{MJ/kg} \times 0.60) \times 3.3\ \textit{Yuan}/\text{kg} = 0.30\ \textit{Yuan}/\text{m}^3$$

Note: the efficiency of straw gas and LPG is 0.5 and 0.6 respectively.

Thus, the project has 101,000 *Yuan* of economic benefit every year.

5.5.3 Environment benefit

Since the remainding corn stalks are partly utilized, not only the straw problem is effectively solved, but scene, pollution, danger of fire and hygiene condition of the village have been improved.

Due to the development of rural economy, fossil fuels such as coal and oil are more and more widely used for domestic. The straw gasification technology provides an efficient way to solve the problem of fossil fuel replacement and pollution.

Two tons of coal are needed for one household per year if coal is the only fuel for cooking. More than 400 tons of coal (300 TCE) can be saved by using straw gas. It can be estimated that the annual CO_2 emission reduction is 220 ton and SO_2 emission reduction is 3 ton.

5.5.4 Social benefit

By using the straw gas, the intensity of cooking labor is decreased, and the cooking time is reduced from 3 hours to 1.5 hours per day. The housewives can have more spare time. This technical system can also give a positive affect to rural area for making progress toward township constructions.

5.6 Financial and Economic Analysis

5.6.1 The assumption of analysis conditions

- The project's lifetime is 10 years; construction period is 0.5 year;
- The facilities can be used for 10 years with no heavy repair before the project expiration, and their resume values are not to be considered;
- The social benefit and environment benefit are not considered;
- The prices refer to 1995;
- The standard discount rate is 12%.

5.6.2 Financial cash flow analysis

Table 5.7 shows that IRR of this project is 5.9%, less than the discount rate (12%) and the NPV is minus. So this project is not feasible on the financial analysis. Compared with present value cost, the gas price is a little low, so the project is a boon project. Further analysis is shown in Table 5.8 based on some adjustment.

The gas cost per household will be 30*Yuan* at the gas price of 0.20*Yuan*/m^3 without any subsidy, which can be acceptable to the farmers because 1/4 of fuel cost can be saved in comparison with coal and LPG. The IRR can also reach 17% which can make the project financially feasible.

Table 5.7 Financial cash flow unit: 1,000 *Yuan*, 1,000 m^3

—	First investment	Operating cost	Total cost	Gas production	Benefit	Net benefit	Total present value
1	387.9	10.2	193.3	194.4	19.4	-173.9	-155.3
2		20.3	20.3	388.8	38.9	18.6	-140.4
3		20.3	20.3	388.8	38.9	18.6	-127.2
4		20.3	20.3	388.8	38.9	18.6	-115.4
5		20.3	20.3	388.8	38.9	18.6	-104.8
6		20.3	20.3	388.8	38.9	18.6	-95.4
7		20.3	20.3	388.8	38.9	18.6	-87.0
8		20.3	20.3	388.8	38.9	18.6	-79.5
9		20.3	20.3	388.8	38.9	18.6	-72.8
10		20.3	20.3	388.8	38.9	18.6	-66.8
11		20.3	20.3	388.8	38.9	18.6	-61.4
12		20.3	20.3	388.8	38.9	18.6	-56.7
13		20.3	20.3	388.8	38.9	18.6	-52.4
14		20.3	20.3	388.8	38.9	18.6	-48.6
15		20.3	20.3	388.8	38.9	18.6	-45.2
NPV	i=10%		311.7	2,780		-34.1	
NPV	i=12%		292.7	2,474		-45.2	
IRR	%					5.9	

Table 5.8 Financial analysis under different conditions

analysis assumption		NPV (i=12%) (10^4 *Yuan*)	IRR(%)	Economic feasibility
subsidy of 0.14 million *Yuan*	gas price (*Yuan*/m^3)			
yes	0.10	-45.2	5.9	unfeasible
yes	0.15	73.9	20.9	feasible
no	0.15	-46.6	8.5	unfeasible
no	0.20	70.9	17.0	feasible

Table 5.9 Economic cash flow unit: 1,000 *Yuan*, 1,000 m^3

Year	First investment	Operating cost	Total cost	Gas production	Benefit	Net benefit	Total present value
1	387.9	16.2	404.1	194.4	50.6	-357.6	-315.6
2		32.3	32.3	388.8	101.1	68.8	-260.8
3		32.3	32.3	388.8	101.1	68.8	-211.8
4		32.3	32.3	388.8	101.1	68.8	-168.1
5		32.3	32.3	388.8	101.1	68.8	-129.1
6		32.3	32.3	388.8	101.1	68.8	-94.2
7		32.3	32.3	388.8	101.1	68.8	-63.1
8		32.3	32.3	388.8	101.1	68.8	-35.3
9		32.3	32.3	388.8	101.1	68.8	-10.5
10		32.3	32.3	388.8	101.1	68.8	11.6
11		32.3	32.3	388.8	101.1	68.8	31.4
12		32.3	32.3	388.8	101.1	68.8	49.0
13		32.3	32.3	388.8	101.1	68.8	64.8
14		32.3	32.3	388.8	101.1	68.8	78.9
15		32.3	32.3	388.8	101.1	68.8	91.5
NPV i=10%			583.7	2,780		135.7	
NPV i=12%			552.0	2,474		91.5	
IRR(%)						17.4	

Present value cost of straw gas (*Yuan*/m^3): C1=583.7/2780=0.21 (i=10%)
C2=552.0/2474=0.22 (i=12%)

Repayment period is 9-10 years.

From the economic cash flow analysis, the following results could be obtained: NPV>0, IRR=17.4%, higher than the social discount rate (12%), repayment period is 10 years. Compared with natural gas project with IRR of 12% and repayment period of 8 years, straw gasification project is economically feasible.

The average price of LPG is 3 *Yuan*/kg in 1997, and the heat value of straw gas is about 4.2 MJ/m^3, so the alternative price of straw gas is 0.23 *Yuan*/m^3. Thus, the IRR of this project will change to 13% on the basis of alternative price.

5.6.3 Sensitivity analysis

Table 5.10 Sensitivity analysis

Factor	Variation rate	-20%	-10%	0%	+10%	+20%
Investment	IRR	+36%	+16%	0	-13%	-25%
Operating cost		+15%	+7%	0	-7%	-14%
Gas price		- 42%	- 25%	0	+25%	+40%

To IRR, the most sensitive factor is gas price, the second is investment. The operating cost (including raw material price) has little influence on IRR. The project will be feasible with IRR of 13% at the gas price of 0.23 *Yuan*/m^3. If the investment or operating cost increases 20%, that means 466,000 more *Yuan* on investment and 48,400 more *Yuan* on operating cost(no cost will change except for the raw material price, the straw price is 0.13 *Yuan*/kg); IRR will reach 13.1% or 15%, which shows that the project is still feasible.

5.7. Conclusion and suggestion

1. In the viewpoint of financial analysis, the project is financially unfeasible. So the straw gasification system doesn't have the capability to be commercialized.

If the gas price could be raised to 0.20 *Yuan*/M^3, the IRR will reach 17% without any subsidy in financial analysis, which is higher than the standard discount rate, thus the project will have commercial potential.

2. From the economic analysis, the NPV is 91,500 *Yuan*, IRR is 17.4% which is higher than the standard discount rate of 12%, and the repayment period is 10 years. With higher gas price, policy support and environmental and social benefits, this project will be entirely feasible and can be commercialized.

3. Taking into account that the project is newly developed and lacks operating experience, the demonstration scale should be enlarged, problems on technique and management should be solved step by step to help it reach commercial operation stage. Due to the large amount of investment, it is suggested that the government should give some political and financial supports during the demonstration phase.

Attached pictures show a Model XFF-2000 straw gasification system for suppling 216 households in Tengzhai village, Huantai county, Shandong Province,designed by Energy Research Institute, Shandong Academy of Science.The System has been applied in 150 villages in China.





CHAPTER 6 Biogas Supply and Comprehensive Utilization —Economic Evaluation of Biogas Project in Xinghuo Breeding Farm[1]

6.1 Case selection

6.1.1 Location of the site

The demand of meat, livestock, and eggs increases greatly as people's income increases, which is the result of China's economic reform policy. In order to meet the need China government promotes the development of the Vegetable Basket Project (Cai Lanzi Gongcheng), which encourage the development of livestock and vegetable plantation to provide the need in cities.

Large-scale livestock development has also aroused environmental pollution issues. The biogas project is one of the technical feasibility options to deal with the discharge from livestock farms. It is not only a project for biogas production for energy consumption but also produces organic fertilizer and fodder at the same time.

As one of the big cities in China, Shanghai’s suburb is the base for Vegetable Basket Project. Xinghuo Farm biogas project is one of the good practice in China for biogas project and for biomass comprehensive utilization. Therefore it is selected as the point for case study.

Located in Fengxian County of Shanghai City, the Xinghuo Farm covers an area of 21.67 km^2 with employees of more than 6,600 and residents of 3,900 household (see Figure 6.1). There are three cow farms in it.

6.1.2 Social and economic development and environmental situation

The farm was established in 1959 as a beach-cultivated farm. The farm has become a comprehensive company with agriculture, livestock, industry and trade.

[1] This report is a technology assessment report. It is not a post evaluation report. The date used in this case are based on the case of Xinghuo Farm but are not restricted to it.

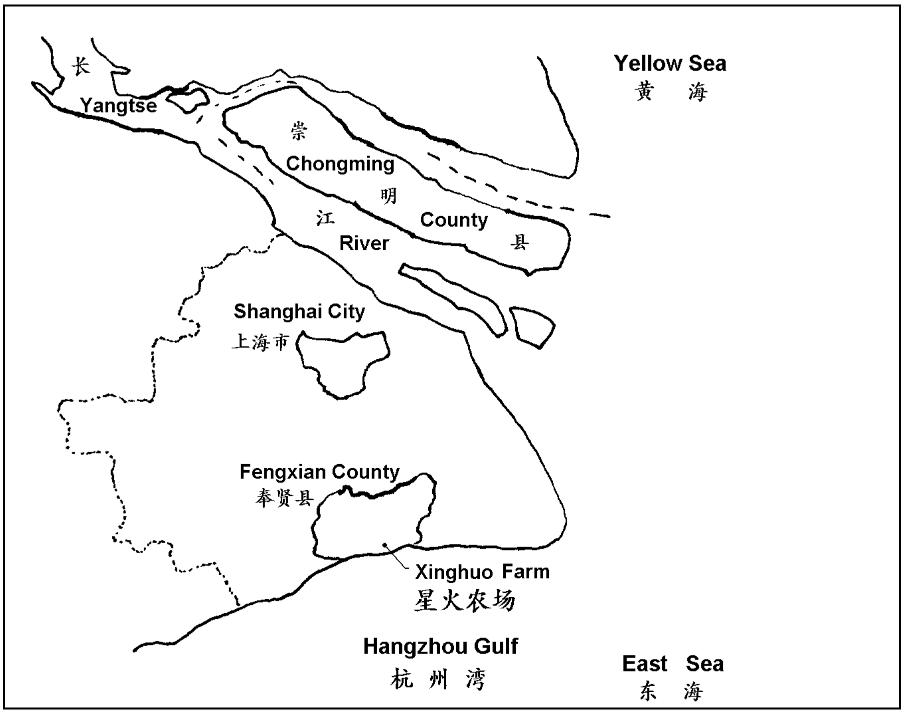


Figure 6.1 Sketch map of Xinghuo Farm location

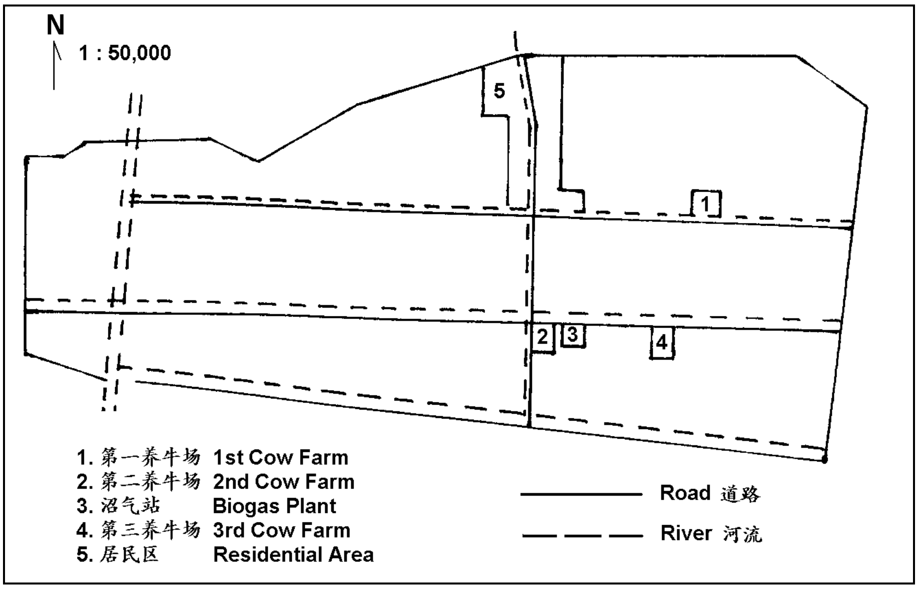


Figure 6.2 Sketch of Xinghuo Husbandry Farm

Up to 1995, its fixed asset valued 0.16 billion *Yuan* and social gross product reached 0.36 billion *Yuan*.

6.1.3 Resource base and availability

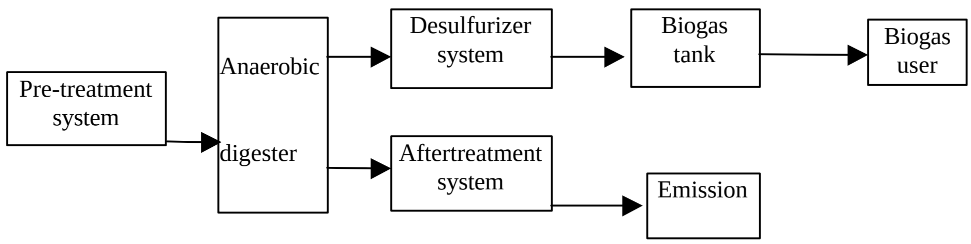
For livestock, the farm has three cow branches raising 2,000 milk cows and a pig branch raising 25,000-30,000 meat pigs. The farm annually provides Shanghai City with more than 6,000 tons of milk and 3,000 head of meat pigs. The dung produced by the livestock farms is about 31,000 ton annually.

6.2 Techno-economic Feature of the Biogas Works

6.2.1 Technological process

In order to dispose of the cow excrement from the three cow branches, the farm decided to built a medium-sized biogas plant in the early 1990s. The plant finished partly and began to produce biogas in 1991.

Figure 6.3 shows the flow diagram system. Dung is pretreated in the pretreatment system, then pumped into digester. Biogas, liquid and solid sludge was produced. Biogas is treated in the desulfurizer system and then provided to users cooking and others. Liquid and solid sludge is used as raw material for biomass comprehensive utilization and to produce fertilizer and feeder. After that it was discharged to farmland for fertilizer utilization or discharged to rivers after other post treatment.



6.2.2 Technoeconomic indicators

The biogas plant consists of six digesters of 450 m^3 each with a total capacity of 2,700 m^3 and storage tanks of 1,400 m^3. Thirty-one thousand tons of cow excrement and 4,380 tons of chicken excrement, as well as 3,000 tons of industrial wastes are disposed annually. Now 3,268 of the households and some firms in service sector in the farm use biogas as fuel.

Table 6.1 Technoeconomic indicators

Volume of the digester (m^3)	2,700
Annual biogas output (m^3)	739,200
Initial investment (million *Yuan*, 1995, Financial assessment[a])	9.12
Construction Period (year)	1
Annual Operation cost (million *Yuan*, 1995, Financial assessment[a])	0.73
Which year to reach whole capacity	second year
Biogas price (*Yuan*/m^3, 1997)	for household, 1.35 *Yuan*/m^3; firms, 2.2 *Yuan* /m^3

a. It is calculated based on the investment in 1990 by the help of price indicators.

6.3 Investment

The total investment of the plant was 9.12 million *Yuan* (1995 price), while 3.74 is subsidy by government, 5.38 by farms themselves. The initial investment and its distribution are given in Table 6.2. It is 13.27 million *Yuan* in economic assessment.

Table 6.2 Initial investment and distribution

Items	Financial (1,000 *Yuan*)	Economic (1,000 *Yuan*)
Civil construction	4,510	5,400
Facility pipeline and installment	3,680	5,840
Management	360	160
Land cost	210	510
Comprehensive utilization	560	560
Feasibility study	0[a]	1,250
Total	9,120	13,720

Note: Feasibility study cost is usual under the management cost in financial assessment in China Case.

Table 6.3 Investment source in financial assessment (1000 *Yuan*, 1995)

	Amount of investment	percentage (%)
Total investment	9,120	100
Government subsidy	3,740	41
Investment from farms[a]	5,380	59

a It is 4.82 million *Yuan* if there are no comprehensive utilization system.

6.4 Operation Cost and Benefit

6.4.1 Operation costs

The annual operation cost is 730,000 *Yuan*, including raw material, energy and water, labor cost, maintenance and others, as shown in Table 6.4 in detail. It was 767,000 *Yuan* in economic analysis.

Table 6.4 Operation cost for typical biogas project (1000 *Yuan* in 1995)

	Financial	Economic
Raw material	202	202
Energy and water	184	210
Labor cost	178	188
Maintenance	62	62
Others	104	104
Total cost	730[a]	767

a It was 616,000 *Yuan* if there are no comprehensive utilization system.

6.4.2 Benefit

Xinghuo farms benefit from the project on two aspects: (1) sell the products it produce as biogas, fertilizer and feeder, and (2) improve the environment. It was 2.74 million *Yuan* in economic analysis, in which 1.44 million from biogas, 67,000 *Yuan* from fertilizer, 269,000 *Yuan* from feeders, and 967,000 *Yuan* of environmental improvement (not including the benefit from CO_2 abatement).

We further analyzed the global environment benefit of the biogas project since it not only provides benefit to environment and local economy, but has benefit to global environment. We use LPG as baseline for analysis. The main indicator of the baseline is showed in Table 6.6. Calculation results showed that the abatement cost of biogas project to abatement CO_2 emission is 293 *Yuan* for per tone of Carbon of CO_2.

We also analysis the benefit from the perspective of the farm. Results showed that the annual benefit for farms was 1.98 million *Yuan* is we use the price of LPG for the substitution price of biogas while it was 1.07 million *Yuan* is the farm regulated price in 1993.

Table 6.5 Benefit of the biogas station-economic analysis (1000 *Yuan*)

Biogas	1,441
Fertilizer	67
Feeder	269
Avoided environmental cost	967
total	2,744

Note: As for avoided cost see ITEESA's report to IDRC for more detail.

Table 6.6 Baseline for CO2 abatement cost analysis

Total investment requirement	1,810,000 *Yuan*
Life cycle for analysis	20 years
Annual LPG consumption	339 ton
Annual operation cost	903,000 *Yuan*

Table 6.7 Benefit of the biogas station-financial analysis form perspective of farmer (1,000 *Yuan*)

	LPG substitution price	Farm regulated price
Farm benefit in baseline case	1,980	1,067
Farm benefit without comprehensive utilization	1,644	731
Farm benefit without environmental fee	1,826	913
Farm benefit without environmental fee and without comprehensive utilization	1,441	528

Table 6.8 Benefit of the biogas station-financial analysis from perspective of farmer (1000 *Yuan*)

	LPG substitution price	Farm regulated price
Biogas station benefit in baseline case	1,777	864
Biogas station benefit without comprehensive utilization	1,441	528

6.5 Financial and Economic Assessment

The result of economic assessment is shown in Table 6.9. The NPV of baseline is 760,000 *Yuan* while the IRR was 13%.

Sensitive analysis showed that the project is sensitive to initial investment and benefit. If the initial investment increased by 10% or the benefit decreased by 10%

the IRR of the project will become 12%. On the other hand, if the investment decreased by 10% or the benefit increased by 10% the IRR of the project will become 15%, which is higher than 12% of the investment criteria.

As the development of biogas technology the initial investment will be decreased which has been demonstrated by the biogas project practice in China. If the investment decreased by 10% the IRR of the project will become 15%. This means the project may well become a good project.

Table 6.9 Economic assessment and sensitive analysis

		NPV (1,000 *Yuan*)	IRR (%)
Baseline case		755	13
Initial investment	increase by 10%	−470	11
	decrease by 10%	1,980	15
Operation cost	increase by 10%	251	12
	decrease by 10%	1,259	14
Benefit	increase by 10%	2,560	15
	decrease by 10%	−1,049	11
1.1 million subsidy from international society		1,740	14

Result of financial assessment showed that the NPV of the project will be 78,000 *Yuan* in baseline case while the IRR will be 12%, as shown in Table 6.10. This means that in case the farmed has surplus investment resource the return of investment in biogas station will be slightly higher than the return from deposit the same amount of money in the commercial bank.

We further analyzed the impact of different policy measures. The results showed that

1) Initial investment subsidy is helpful for the farms to adopt the biogas technology to treat discharge from livestock farms (Scheme of 2 and 4);

2) If farm regulated price is applied, the financial benefit from the biogas station is not high. As a result it will be encourage the farms to invest in the biogas technology.

3) Result showed that comprehensive utilization is not the key factor for the financial and economic performance while it affect the financial performance of biogas station.

4) Farm will have less incentive if the regulation on environmental fee is not fully implemented.

5) If China can get initial investment subsidy from outside at a amount based on the CO_2 abatement cost of biogas station the farms and China government will have the incentive to promote and to do the biogas station.

Table 6.10 Financial assessment and sensitivity analysis

	NPV (1,000 *Yuan*)	IRR (%)
Base case: no government subsidy,LPG substitution Price, environment fee	78	12
Scheme 1: no government subsidy, farmed regulated price, environment fee	−5,920	−3
Scheme 2: with government subsidy,LPG substitution price, environment fee, with comprehensive utilization	3,420	23
Scheme 3: with government subsidy, farmed regulated price, with environment fee, with comprehensive utilization	−2,590	2
Scheme 4: with government subsidy,LPG substitution price, environment fee, without comprehensive utilization	2,460	21
Scheme 5: with government subsidy, farmed regulated price, with environment fee, without comprehensive utilization	−3,540	
Scheme 6: without government subsidy,LPG substitution price, without environment fee, with comprehensive utilization	−940	10
Scheme 7: without government subsidy, farmed regulated price, without environment fee, with comprehensive utilization	−6,940	
Scheme 8: with international subsidy,LPG substitution price, environment fee, with comprehensive utilization	1,060	14

From the perspective of a biogas station, the financial performance is shown mainly from the annual balance between cost and benefit. The calculation shows that if use the LPG substitution price the biogas station have surplus. If applying the farmed regulated price the biogas station will has limited surplus with comprehensive utilization and did not have surplus in the case of without comprehensive utilization.

Table 6.11 Financial analysis from the perspective of biogas station

Scheme 1: LPG substitution price and with comprehensive utilization	7,709
Scheme 2: Farm regulated price and with comprehensive utilization	986
Scheme 3: LPG substitution price and without comprehensive utilization	6,079
Scheme 4: Farm regulated price and with comprehensive utilization	−644

6.6 Social Environmental Benefit

6.6.1 Environmental benefit and GHG abatement

The construction of biogas station improve the environmental quality off farm. After the establishment of the biogas station the discharge from the farms reach the nation environment standard.

The biogas station not only treats the dung of the farm itself, but also the residual discharged by Shanghai Haixing livestock farm. As a result it avoids the environment treatment cost.

The biogas station has the benefit of substitution of fossil fuel, such as coal, LPG, electricity.

The biogas station also have positive global environmental benefit. Using the LPG as the baseline the CO_2 abatement from biogas technology will be 3,753 tons of carbon in the life cycle of the biogas station.

6.6.2 Social benefit

Biogas project has many social benefits. It reduces the time needed for cooking, so provides more leisure time for a household. On the other hand, since coal stove is substitute in the case of Xinghuo Farm household does not have to store the coal cake in the corridor of the building, which results in good environmental quality in the corridor and in good neighborhood relationship.

The biogas station also improves the air quality of the farm, so avoids the cost of disease treatment fee and cost from labor loss.

6.6.3 Benefit to women working and health conditions

Since biogas replaces coal, the emission from coal combustion is avoided. It is estimated that the avoided discharge of coal dust is about 10 ton annually, with an avoided cost of 29,000 *Yuan* to move it to place government regulated.

Biogas stove to substitution coal stove also reduce the working intensive of the women on cooking.

6.7 Conclusion and Recommendation

Under the continuing effort of the technicians and managers both in institutions and in government large and medium biogas technology has had the initiative to survive in the market economy environment.

Under the economy institution framework the financial and economic indicators of the biogas technology which is a environmentally sound technology still cannot incentive the Chinese and farm to adopt the technology in large scale.

Given the global environmental benefit biogas technology provides if international subsidy can be provided (under the base of cost of biogas technology to abate CO_2 with LPG as a baseline) farms and Chinese government will have sufficient incentive to promote the development in large scale.

Without international incentive China itself has the reason to promote the development of the biogas technology from it own seek. In this case it is help to reinforce the implementation of environmental regulation.

Annex

Annex Table 1. Cash flow of economic assessment for biogas project (1000*Yuan*, 1995)

Year	Initial Investment	Operation cost	Benefit	Net benefit
1	13,720			-13,720
2		767	2,744	1,978
3		767	2,744	1,978
4		767	2,744	1,978
5		767	2,744	1,978
6		767	2,744	1,978
7		767	2,744	1,978
8		767	2,744	1,978
9		767	2,744	1,978
10		767	2,744	1,978
11		767	2,744	1,978
12		767	2,744	1,978
13		767	2,744	1,978
14		767	2,744	1,978
15		767	2,744	1,978
16		767	2,744	1,978
17		767	2,744	1,978
18		767	2,744	1,978
19		767	2,744	1,978
20		767	2,744	1,978
NPV(12%)				755
IRR				13%

The following pictures show a large biogas plant of total capacity of 2700 M3, h 6 digesters of 450M3 each and one gas tank of 1400 M3, in Xinghuo Farm, Shanghai. The biogas station supplies biogas to 3268 households and some service firms as their cooking fuel in the Farm. In addition, the biogas is comprehensively utilized and has multi-benefit by using the waste sludge and liquid as organic fertilizer and feedstuff.

CHAPTER 7 Biogas Project for Central Gas supply
--Tech-eco analysis of Biogas Project, Neijiang Agricultural Science Institute, Sichuan

7.1 Introduction

Neijiang is a prefecture city of Sichuan Province. It is located in the middle of Sichuan Basin, 220km far from Chengdu, the capital of Sichuan Province. Chengyu highway runs through the whole city. Neijiang has 9 counties(cities, districts) with large population, in which there are 5 counties(cities, districts) have population over 1 million each. Agriculture is the main industry, Neijiang is the production base of grain, oil, pig, sugar of Sichuan Province.

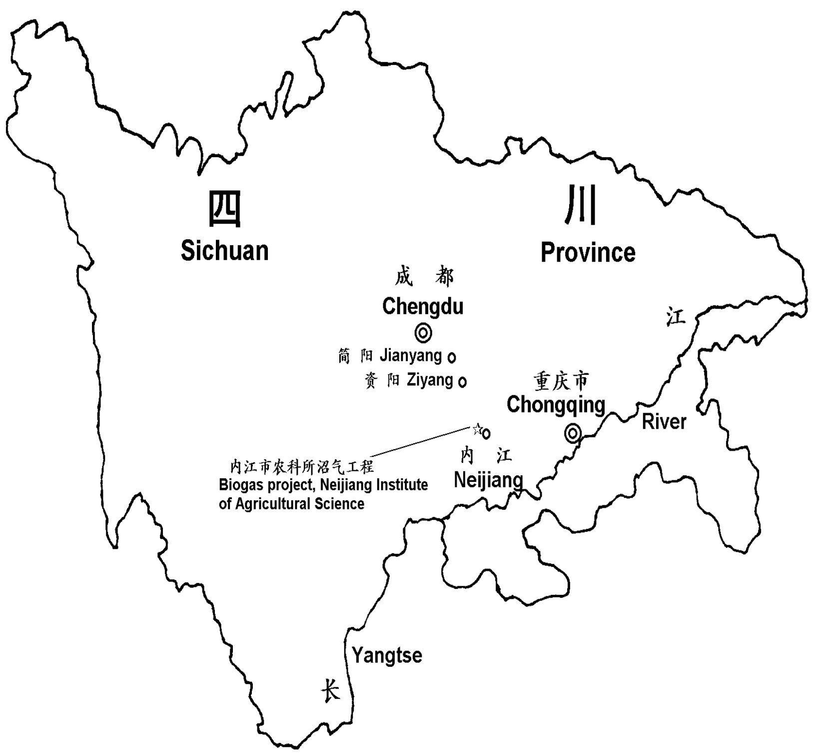


Fig. 1 Sketch Map of Neijiang Institute of Agricultural Science location

Neijiang Agricultural Science Institute is a city level institute with 300 agricultural scientific and technical staff, it covers an area of 300 *mu*, 7.5km far from urban district. There is a 90-head cow diary farm in the institute, the annual milk output is 200 tons. In the past, the untreated cow dung with weed seeds was directly poured out into the Tuo River, the water was polluted. To solve the problem, a 416m^3 biogas project was built in 1991 with the investment of city government and environment protection Bureau. Each allocated 150,000 *Yuan* and 10,000 *Yuan* respectively in 1990.

7.2 Technical and Economic Characteristic of Biogas Project

7.2.1 Technological design and system description

The technology applied in this biogas system is the anaerobic digestion at normal temperature(Fig. 7.2) Cow dung is the raw material. First the cow dung goes through fence filter into the preprocessor for counting and adjusting, then the waste is pumped into the anaerobic reactor which has mixing device for anaerobic fermentation. Generated gas is stored in the gas tank. A 400-meter pipeline will transfer the gas to 65 households of the Institute for living energy. The waste liquid and slurry is stored in fertilizer tank for fertilizing the testing fields inside the Institute.

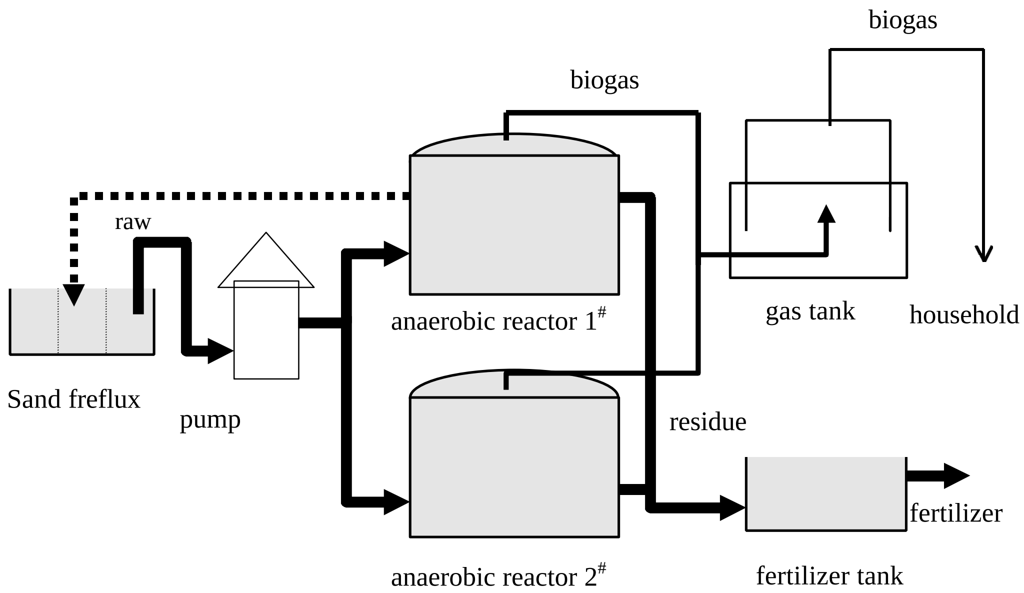


Fig. 7.2

The biogas system covers an area of 1 *Mu* with total capacity of 416m^3. It consists of 2 anaerobic reactors with volume 150m^3 each, a 50m^3 gas tank, a 36m^3 fertilizer tank and a 30m^3 preprocessor.

7.2.2 Main technical and economic characteristics

Total investment: 160,000 *Yuan*. Project life: 20 years. Treating efficiency: 5 tons dung of 100 heads cow each day. Water stagnant period: 40 days. Biogas output at normal temperature: 100m^3/day.

7.3 Investment and Benefit

7.3.1 Investment

Total investment is 160,000 *Yuan*(1990's price), which includes design cost 10,000 *Yuan*, pipeline and equipment 100,000 *Yuan*, construction cost 50,000 *Yuan*. 150,000 *Yuan* came from the city government, 10,000 *Yuan* from environment protection bureau.

The system covers an area of 1/15 ha., the land was original testing field owned by the Institute. According to the formal use of land, 7,500 *Yuan* net income could be gained 1 hector, therefore, the opportunity cost of this system is 7,500 *Yuan* × 1/15= 500 *Yuan*

7.3.2 Operating cost

The system has been working well since 1991, the operating cost includes:

- Managing cost: one staff is in charging of the daily operation, managing and maintaining of the system, including raw material preprocessing, material inlay, material outgo, gas supply at certain time, pipeline and equipment maintain, repairing etc.. The salary of the worker is 3,000 *Yuan* per year.
- Electricity cost: Electricity used by the system: 1,700 kWh, electricity price at 1990: 0.25 *Yuan*/kWh, the total electricity cost: 675.00 *Yuan*/yr.
- Maintenance cost: about 1,000 *Yuan* each year.
- Total operating cost per year: 4,675 *Yuan*.

7.3.3 Economic Benefit

Direct economic benefit for Neijiang Agricultural Science Institute:

- Management Fee collected from the household: each household is asked to hand 10 *Yuan* management fee per year as the supplementary cost of system operating cost. Total sum of money: 10 *Yuan* * 65= 650 *Yuan*.
  Reducing fertilizer cost: after anaerobic digestion, cow dung could be directly applied to the field as fertilizer, therefore 50 trucks of fertilizer could be reduced, one truck of fertilizer costs 30 *Yuan*, the cost reduced: 1,500 *Yuan*.

Total: 2,150 *Yuan*.

Social economic benefit:

- Value of biogas: biogas output is 18,000m^3 /yr. At present, 40% residents of Neijiang use natural gas, but the Institute is a little bit far from urban area(7,000m), it is difficult for them to use natural gas recently. In 1990, people in the Institute and city took LPG as fuel, the price of LPG is 45 *Yuan* each bottle. The price of Biogas is 1.25 *Yuan*/m^3. The total benefit of biogas is 22,500 *Yuan*/yr.

7.4 Economic Benefit Analysis

7.4.1 Financial analysis

The investment of the project was government financial allocation, there is no need to be paid back.

Biogas is free for the staff of Institute. Every year, the management fee and reduced fertilizer cost are 2,150 *Yuan*, it is not enough to compensate operating cost of the system 4,675 *Yuan*. If revenue and expenditure are balanced, the charge of biogas at least will be 0.14 *Yuan*/m^3 which is affordable for the staff, and it will be adjusted along with the operating cost increase.

If considering taking primary investment back, the price of biogas should at least be 0.584 *Yuan*(20 years depreciation).

If the primary investment was loan, interest is 10% in 1990, the present value of total cost is 181,637 *Yuan*, the present value of total biogas output is 153,244m^3, the profit and loss balance price is 1.185 *Yuan*(dynamic). It is cheaper than that of LPG.

7.4.2 Economic analysis

Taking dynamic analysis of the biogas project, its cost and benefit could be adjusted as follows:

- Investment: 160,000*Yuan*.
- Operating cost: Besides the cost of 4,675*Yuan*, the opportunity cost of land should be included, i.e., the reduced agricultural income due to setting up biogas project, the figure is 500*Yuan*/year. Therefore, the operating cost is 5,175*Yuan*/yr.
- Economic Benefit: Taking into account the values of biogas and as well the savings on fertilizer expenses, the economic return of this biogas scheme could be 24,000*Yuan* (the management fee collected from the users has already been included as part of the values of biogas and was no longer treated as benefits).

Table 7.1 The Cash Flow Analysis(*Yuan*, 1990)

Year	Establishment Investment	Operating Cost	Benefit	Net Benefit
1	160,000			−160,000
2		5,175	24,000	18,825
3		5,175	24,000	18,825
4		5,175	24,000	18,825
5		5,175	24,000	18,825
6		5,175	24,000	18,825
7		5,175	24,000	18,825
8		5,175	24,000	18,825
9		5,175	24,000	18,825
10		5,175	24,000	18,825
11		5,175	24,000	18,825
12		5,175	24,000	18,825
13		5,175	24,000	18,825
14		5,175	24,000	18,825
15		5,175	24,000	18,825
16		5,175	24,000	18,825
17		5,175	24,000	18,825
18		5,175	24,000	18,825
19		5,175	24,000	18,825
20		5,175	24,000	18,825
21		5,175	24,000	18,825

Assuming that the construction period for biogas scheme lasts for one year, its economic life lasts for 20 years with no residues and the social discount rate equals 10%, Table 7.1 provides some economic indicators of this scheme and the result can be summarized as following :

Net Present Value(NPV) = 243.5 *Yuan*
Internal Rate of Return(IRR) = 10.03%.

It can be judged from above indicators that the scheme just lies at its break-even point and could be seen feasible and cost-effective.

7.4.3 Sensitivity Analysis

Since the scheme is subsidized as being part of the welfare system in agricultural scientific research institute, it does not aim to make any financial profit and in fact different financial returns have been calculated in association with different prices of biogas in the above financial analysis. The following points only provide sensitivity analysis from an economic point of view:

The sensitivity analysis could be studied from following three aspects:

- ***Establishment Investment***: Since the prices of raw material and labor forces are easily changeable and in most cases they change in same direction, the change of total investment can be used to reflect the price changes.

- ***Operating Cost***: The operating cost mainly includes salary, electricity, spare parts and maintenance cost, of which salary accounts for the highest part. Since the scheme has a limited operating cost, it can also be assumed to change in same direction.

- ***Benefit***: The value of biogas accounts for the major part of the benefit. The price for purchasing the manure would change but can be neglected due to its small portion. There are two factors which affects the biogas values: first is the yield of biogas, this would however maintain stable with several years of operation, second is the price of biogas which would fluctuate with the price of liquefied petroleum gas (LPG).

The result of the sensitivity analysis can be tabulated as following:.

Table 7.2 Sensitivity analysis

Changing Factors		NPV(Yuan)		IRR	
		Changes	%	Changes	Percentage point
Base case		243.5		10.03%	
Total investment	+10%	−14,302	−5,873.5	8.7%	−1.33
	−10%	14,789	5,873.5	11.6%	1.57
Operating Cost	+10%	−3,762	−1,545	9.6%	−0.43
	−10%	4,249	1,545	10.4%	0.37
LPG price	+10%	17,658	6,151.7	11.7%	1.67
	−10%	−17,171	−6,151.7	8.2%	−1.83

As can be seen from the above table, the economic return for this scheme is most sensitive to LPG price, and secondly to total investment. Due to the low operating cost, it is less sensitive with changes of operating cost but still have an impact on the absolute value of NPV.

There are some weaknesses in scheme design for some of the equipment and buildings have not been fully utilized. Lower investment would be possible if the design could be further improved. The LPG price would fluctuate with market supply and demand, and the possibility for a foreseeable decrease in its price is quite limited. If the biogas is valued at LPG price, the scheme would show a very positive economic and financial return. In addition, if the fermented residues could be better used, higher economic return would then be expected.

7.5 Environmental and Social Impact

7.5.1 The Environmental Impact

The construction for the biogas scheme would reduce the environmental harm that the open heap for cattle manure might bring to the research institute and its neighboring area. When the cattle manure has been fermented in the pool, it then becomes an effective resource and the weed seed contained in cattle manure would not bring much harm to the crops. Further more it can also reduce and finally eliminate the manure's pollution to drinking water in Neijiang City. It is expected that with this scheme the institute can reduce annually its discharge of cattle manure by 1,200 tons.

The scheme can save a lot energy through reduced consumption on coal, LPG and electricity, it can also reduce annually the discharge of carbon dioxide by 50 tons when the gas was calculated in terms of LPG.

7.5.2 The Social Impact

Though the biogas at the research institute can not be provided on full time basis the local resident will in the end definitely reduce their consumption on other alternative fuels. According to a typical household survey the average household (normally with a size of 4 people) could save each month half a bottle and each year 6 bottles of LPG. The annual saving per household can reach 270 *Yuan*. If multiplied by 65 households in the institute the total saving can reach 17,550 *Yuan*.

In addition to the above saving, the fuel quality and life quality of the institutes employees would also get improved to certain degree.

7.5.3 Women's impact

With the introduction of biogas, it can greatly reduce the coal consumption and lessen the labor input in transportation for coal and LPG. It will liberalize women from the traditional cooking which is always time-consuming and labor intensive.

7.6 Conclusion and Recommendations

1. The scheme was completed in earlier time with inappropriate technical design and insufficient fund, There exist many weaknesses in terms of the scheme integrity and compatibility. In spite of that, the scheme can still generate promising economic benefit if it is run on a market basis. This has proven that Livestock Station can run successful scheme. Currently there are few such stations which can self-finance biogas schemes and a joint effort from the government, financial institutes and international communities.

2. The governmental authority on agricultural environment should supervise closely the environmental quality of livestock stations and improve their environmental awareness through administrative and economic measures. Biogas scheme should be encouraged for manure utilization and environmental protection. Close environmental supervision for those research stations who have constructed biogas schemes should also be strengthened. The pollution fine and penalty system in industry sector has led many enterprises to build biogas schemes using their organic discharge as resources. This should be of great relevance for agricultural sector.

3. The governments relevant authority should strengthen the dissemination and extension of the new technology and the comprehensive utilization on biogas. The three issues in terms of technology, system compatibility and effectiveness reflected in the above biogas scheme have now found their respective solutions and the construction of new schemes can definitely generate more positive results.

CHAPTER 8 Landfill Gas Used for Power Generation in Tianziling Refuse Landfill in Hangzhou

8.1 Site Selection and Relative Accordance

8.1.1 Natural conditions

Hangzhou, the capital of Zhejiang Province, is located in the middle of Zhejiang with the area of 16,596km^2. Plains and lakes are its main geological characteristics. Hangzhou is a beautiful city, whose green area in 1995 was 7,737 hectares. The climate of Hangzhou is warm and moist, and the precipitation is abundant. The annual average temperature is 16.6°C, 33.8°C in summer and 3.6°C in winter. The annual sunshine hour is 1,912 and the precipitation is 1,149mm. Thus Hangzhou is in subtropical climate zone.

8.1.2 Economy & social development and environmental condition

The administrative division in Hangzhou city includes 5 districts, 7 counties, 134 ganizational towns, 96 xiangs and 4,681 villages with total population of 5,979,600 and 1,825,500 families. The population in urban areas is 1,435,200 and family number is 460,600, in which the non-agriculture population is 1,213,800 and agriculture population is 221,400.

The economy of Hangzhou mainly depends on light industry, textile, electronics, tourism and medicament, which is developing quickly in recently years with the increase rate of GDP of 19%. In 1995 the GDP of the city reached 76.2 billion *Yuan*, namely 10,838 *Yuan* per capita. The financial revenue was 5.512 billion *Yuan*. In the same year the average income of staff in urban areas was 6,619 *Yuan*, while the net income per capita was 3,641 *Yuan* for peasants. 98.9% and 81.2% population were with access to tap water and gas respectively.

In recent years, the environment in Hangzhou has been improved greatly with the economy development. The green area in the city increases year by year, and the contents of SO_2 and TSP in the air reduce also. In 1995, the rates of disposing and recovering waste gases, waste water and ash powder were 64.7%, 68.8% and 84.8% respectively. The daily capability of disposing residential waste water reached 895,000 tons, and the rate of residential waste cleared was over 60%.

8.1.3 Refuse resources and their availability

With the continuous development of the economy and the increase of population, the quantities of municipal residential solid refuse in Zhejiang Province and Hangzhou City are increasing at the annual rate of about 10%. By 1995, the daily residential refuse cleared in Hangzhou was 1,781 tons, and 650,000 tons in the year. While the municipal residential refuse cleared in Zhejiang Province reached 4.9 million ton in 1995 (see table 8.1). At present, simple landfill, harmless landfill and dump are still major methods for refuse disposing. Tianziling Refuse Landfill (TRL) mainly disposes residential refuse of Hangzhou City. In the future, with the economy development, population increasing and urbanization, the total quantity of residential refuse will increase.

Table 8.1 Resources of residential solid refuse in Zhejiang Province and Hangzhou City (Mt)

	1990	1991	1992	1993	1994	1995
Refuse cleared in Zhejiang Province	2.51	2.88	3.41	3.72	4.43	4.90
Refuse cleared in Hangzhou City	0.476	-	0.51	0.54	-	0.65
Night soil disposal in Zhejiang Province	1.84	2.60	2.28	3.04	3.11	2.41
Night soil disposal in Hangzhou City	0.273	-	0.26	0.3	-	0.22

In mix residential refuse in Hangzhou City, the inorganic substances is about 6%, while organic substances is 31%, in which food waste occupies a major part. The aquifer of mix refuse is over 20% (see table 8.2).

Table 8.2 Contents of residential refuse in Hangzhou City (%)

Refuse	food	paper	plastics	fiber, gross	total of organic substance	stove ash, dirt	glass	metal	total of inorganic substance
Content	25	3	1.5	1.5	31	65	2	2	69

Hangzhou is with advanced economy, beautiful scenery, and good natural environment, however, the resource of energy is relatively scare. The gap between demand and supply depends on allocation and transportation from other provinces. Therefore, landfill gas used for power generation can not only preserve the beautiful natural environment for tourism, but also be a measure of energy supply.

8.1.4 Basic conditions of project of using landfill gas for power generation in TRL

TRL is located in the suburb north to Hangzhou, and is valley-shaped with the total area of 160,000m^2. TRL was put into operation in 1991. The height level of initial operation layer was 54m, and it is 90 meters now. The operation of filling will continue till 2004. By that time the height level of operation layer will be 165m and the total capability of landfill will reach 6 million m^3 with the highest depth of about 50m. The designed capacity of landfill for TRL is 1,288 tons for one day, that is, 470,000 tons annually. However, the actual amount of refuse disposal is 70% of the designed capacity. By the end of 1995, there have been 1.4 million tons of refuse disposed in TRL. Due to several reasons such as transportation and recovery, the component of refuse disposed in TRL is a little different from that of mix residential refuse of Hangzhou City, that is, the perception of the organic substances is relative higher (see Table 8.3).

Table 8. 3 Component of the refuse disposed in TRL (%)

Component of refuse	Content	Component of refuse	Content
food	46.11	stove ash	45.49
paper	1.51	glass	1.4
plastics	1.54	metal	0.9
animals	0.98	tile stone	0.89
Textile	1.18	total inorganic substance	48.68
total organic substance	51.32		

Because of large precipitation in Hangzhou, the water content of the refuse in TRL is relatively high, about 40%, which can even reach 50-60% in the rain season. The daily average quantity of leachate (namely percolating water) is 300-400 tons in the dry season, while 700-800 tons in the rain season.

TRL is a relatively advanced large-scaled landfill in Zhejiang Province, mainly aiming at disposing the solid refuse of Hangzhou and its surrounding towns. The landfill have been operated for about 6 years before collecting the methane-rich landfill gas, so the gas generated from landfill is basically steady and meets the demand for power generation. It is suitable for case study and demonstration.

8.2 Technical & Economic Characteristics

8.2.1 Technical & technological procedure and description of system

(1) Technical & technological procedure

The basic property for the case are shown below:

flow of gases:	20,000 Nm^3/d
caloric value (LHV):	17.67 MJ/m^3
caloric value (HHV):	19.65 MJ/m^3
H_2S:	25 μg/l
volatile organic substance:	950 μg/l
content of water:	Saturation
output of electricity:	1,400 kW (the net value)

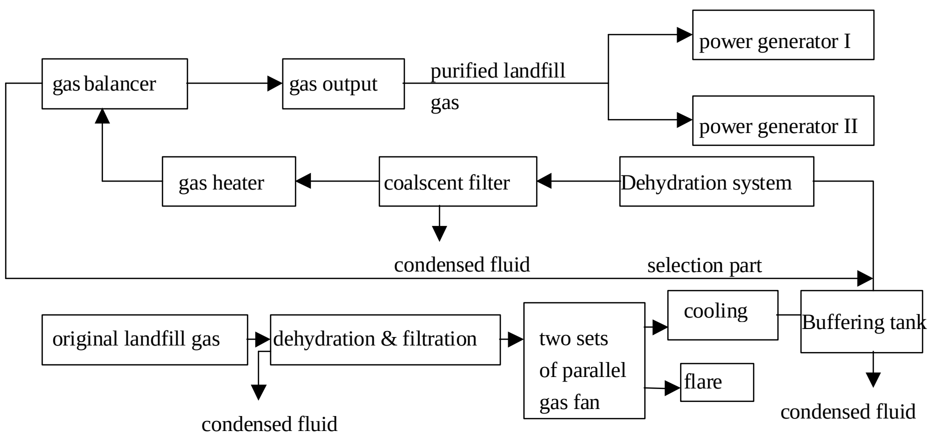


Figure 8.1 Technological process of the landfill gases disposing system

The Collection of Landfill Gas:

According to the measuring and calculation, the collection rate of landfill gas in TRL is about 70%, that is, the daily collected gas can be 9,657m^3. By the mean of digging vertical wells, the collected gas in a day can reach 19,131m^3. The component of landfill gas of TRL includes 54.4% of CH_4, 34.1% of CO_2, 10% of N_2 and 1.3% of O_2. The caloric value per standard cubic meter of methane-rich gas is 19,500 kJ. Due to the high aquifer in the refuse (40%-50%), the ventilation and permeability of the gas in the refuse are very poor. In respect of the commercial utilization, the distance between the wells should be limited within 50m. The average temperature of the mouth of wells should be 40°C. Since the landfill gas is saturated, the collection of the condensed water and its letting out to the drop and filter system are also considered in the collection system.

(2) The parameters of landfill gas collection system are shown below:

The numbers of vertical wells for collecting gas:	10~15
Distance between wells:	40~50 meters
Pump:	1,000 Nm^3/d
Emergency flare(torch):	20,000 Nm^3/d

Disposal of the landfill generated gases

The landfill gas dispose system is shown in Fig. 8 1, and the gas will be disposed until it meets the demands for turbine. The normalized dispose system is installed in an integrated container so that it is easy for local installation and operation on-site.

Power generation with landfill gas

After collected and disposed, the landfill gas will be transferred into the two gas-burning turbine generators. Electricity will be generated on the spot and connected to the grid.

Both generators which are operating parallel have the following technical parameters:

Power output:		760 kW
Stanford 400V generator:		736 kW
Efficiency:		39.05%
Emission:	NO_x	500 mg/m^3
	CO	955 mg/m^3
	VOC	150 mg/m^3
Energy input:		1,888 kW

The turbines and generators are installed in containers, with integrated lubricant system, cooling system, pipeline system, emission muffle, controller, switch screen, electricity utilization and distribution system, protective relay, ventilation equipment, lighting system, etc..

8.2.2 Main technical-economic parameters

The project of landfill gas recovery and utilization is designed to have 20-year life-span, to collect 19,131m^3 of gas in a day. The thermal value of the gas is 19,500 kJ/m^3. The electric power is 1,400 kW, and total operating time is more than 95% of a year.

The total investment of project is 20.75 million *Yuan*, with the annual direct economic benefit of 627,260 *Yuan*.

8.3 Investment

The total investment of project is 20.75 million *Yuan*, including 16.6 million *Yuan* for construction and 4.15 million *Yuan* for technology input. The project occupies land of 1,250m^2. Table 4 shows the initial investment.

Table 8.4 Investment of landfill gases utilization project in TRL (1,000 *Yuan*, price of 1995)

Items	Financial	Economic
Land	75	150
Project Investment construction	450	450
flare for incineration	58	58
Generators and Fans	9,310	9,310
Automatic controlling system and measuring instruments	1,200	1,200
Spare parts, fittings and tools	2,570	2,570
Installation	1,050	1,050
Office equipment, transportation tools	307	307
Technology input	4,150	4,150
Others	1,580	1,580
Total	20,750	20,825

8.4 Operating Cost and Benefit

8.4.1 Operating cost

The operating cost of project includes manual cost, power cost , maintenance and examination cost of the equipment etc.. The operating cost of project is shown in Table 8.5.

Table 8.5 Operating cost of landfill gas utilization project in TRL (1000 *Yuan*, price of 1995)

Items	Financial	Economic
Power, water etc.	650	1,300
Maintenance	1,050	1,050
Salary and bonus	300	300
Management and Others	100	100
Total	2,100	2,750

8.4.2 Benefit

In the project the recovered methane-rich gas is used for power generation connected to grid directly. There are two prices of electricity, peak price and valley price. The prearranged electricity prices are shown below:

Peak price for 14 peak hours:	0.63 *Yuan*/kWh
Non-peak price for 10 hours:	0.17 *Yuan*/kWh
Average price:	0.438 *Yuan*/kWh
Annual electricity sale income:	5,106,900 *Yuan*
Economic analysis price(long-term projection price):	0.80 *Yuan*/kWh

8.5 Financial and Economic Analysis

8.5.1 Financial and economic analysis

Table 8.6 shows the results of financial and economic analysis of the landfill gas utilization project under basic condition. If taking inflation into account, the FIRR is 12.5%, indicating that the project can bring a little benefit. However, without considering inflation, the FIRR is only 8.3%, which is lower than the standard IRR of 12%.

Table 8.6 Results of financial and economic analysis of project

	Financial		Economic	
	NPV(1,000 *Yuan*)	IRR (%)	NPV (1,000 *Yuan*)	IRR (%)
Without inflation	-3,745	8.37	2,523	31.42
With inflation considered *	633.2	12.5	4,216	36.38

*: Inflation rate of operation cost and electricity price is set as 5%.

8.5.2 Sensitivity analysis

Table 8.7 shows the sensitivity analysis of the project. The result indicates that the project is not particularly sensitive for the changes of the investment and operation cost, but comparatively, it is sensitive for the changes of the benefit. Hence the changes of electricity sale and the electricity price will have relatively important influence on the benefit of the project. But it should be noticed that without inflation FIRR is still lower than the standard IRR, even the electricity sale is 10% higher.

Table 8.7 Result of sensitivity analysis of project (with inflation considered)

		NPV (1,000 *Yuan*)	FIRR (%)
Basic case		-3,745	8.37
Changes of investment	+10%	-5,252	7.28
	-10%	-2,238	9.64
Changes of operation cost	+10%	-4,536	7.54
	-10%	-2,954	9.17
Changes of sale	+10%	1,821	10.28
	-10%	-5,669	6.30

8.5.3 Comparison among scenarios

Next is the analysis of several scenarios, which includes different investment patterns, tax reduction or exemption by the government, low-interest loan and subsidy, etc.. Also the scenarios are compared with each other. The conditions of basic scenario are:

Investment: investment from government or equity entirely, without load
VAT rate: 17%
VAAT rate: 8%
Income tax rate: 33%
Years for depreciation: 10
Without inflation considered

8.5.3.1 *Source of investment*

	NPV (1,000 *Yuan*)	FIRR (%)
Basic scenario: investment from government or equity entirely, without load	-3,745	8.37
Scenario 1: 50% from equity & 50% from loan*	-2,979	7.84

*: Interest rate of loan is 12%, payback time is 10 years.

8.5.3.2 *Interest rate of loan*

The following is financial analysis of scenarios with different interest rate of loan. The sources of investment are the same as scenario 1, namely 50% from equity and 50% from loan with payback time of 10 years.

	NPV (1,000 *Yuan*)	FIRR (%)
Scenario 1: full-interest (12%)	-2,979	7.84
Scenario 2: low interest or interest with subsidy (6%)	-964	10.54
Scenario 3: low interest or interest with subsidy (3%)	43.2	12.07
Scenario 4: interest free (0%)	1,051	13.72

8.5.3.3 *Tax rate*

The following is financial analysis of scenarios with various policies of tax reduction or exemption. The investment of all scenarios from No.5 to No.9 is without loan.

	NPV (1,000 *Yuan*)	FIRR (%)
Basic scenario: investment from government or equity entirely, without load	-3,745	8.37
Scenario 5: Income tax free	-1,620	10.58
Scenario 6: VAAT free	-3,589	8.53
Scenario 7: Reduction of VAT & VAAT	2,548	9.66
Scenario 8: VAT & VAAT free	1,636	10.46
Scenario 9: Income tax, VAT & VAAT free	1,527	13.30
Scenario 10: Income tax, VAT & VAAT free, with interest free loan of 50% investment	5,556	19.84

The analysis results of above scenarios show that:

(1) Due to the specialties of the refuse landfill gas utilization project, if the whole investment of the project comes from government or equity entirely as basic scenario, FIRR is 8.37%, which is near the standard IRR of public welfare project. In view of the national economic assessment, EIRR of the project is 10.7%. Thus if the whole investment comes from the government, the project is basically close to economic feasibility standards of the reproducible energy projects which has benefit for environment.

(2) Comparison from scenario 1 to scenario 4 shows that the interest rate of loan can greatly influence the economic feasibility of the project. For refuse landfills, when the interest rate is as low as 1/4 of the rate of basic scenario, the capability of acquiring financial benefits just meets the standard. If the project can be provided free-interest loan, it is profitable. Considering the effects of the refuse landfill gas utilization project on environment, the government or international organizations should provide some loans with low interest, interest subsidy or free interest, which can improve the economic benefit of the project and motivate the enterprise to participate in such projects.

(3) Comparison among the basic scenario and scenarios from No.5 to No.9 shows that the policies of tax reduction and exemption can improve the economic feasibility of the project to some extent. Exemption of income tax or VAT will raise 2 percentage point of IRR. Exemption of all taxes will raise 5% of IRR. Therefore

the policies of tax reduction and exemption are also important measures which can improve the economic benefit of the project.

(4) In scenario 10, when all taxes are free and 50% of the investment is available from interest free loan, the project has excellent economic benefit. Thus the favorable policies on finance is significant for the development and dissemination of such projects.

8.6 Social and Environmental Impact Assessment

8.6.1 Impact on environment and abatement effect

The project of refuse landfill gas recovery and utilization will not bring secondary pollution on environment. On the contrary it is a project of solving the environmental problems. It will solve the main environmental problems, which are caused by refuse landfill gas.

(1) This project mainly collects and incinerates the landfill gas. Without the project, methane, which is the main component of the landfill gas will be emitted directly into the air. Through the project, the amount of methane utilized in a year can reach 2,700 tons, which means during the life-cycle of the project a equivalence of 54,000 tons of methane can avoid being emitted into the air. Since one ton of methane abated equals to abatement of 25 tons of CO_2, the project has great advantage to GHG abatement.

(2) The recovery and utilization of the landfill gas improve the spot environment of TRL and guarantee the local safety and improve the staffs and workers health.

(3) The landfill gas consists of a little volatile poisonous substance. By burning, it can be decomposed and avoid being emitted directly into the air.

(4) Power generation by using landfill gas can not only reduce the pollution caused by the landfill gas directly, but also reduce the pollution caused by using coal and oil for generation indirectly when considered it can be the substitute of coal or oil for generation. Thus it has dual environmental benefits. Through calculation the project can substitute for 4,544 tons of coal, abate 26,720 tons of CO_2 emission and 1,100 tons of SO_2 in a year during its life-cycle.

8.6.2 Impact on the local society

Hangzhou is a tourism city with beautiful scenery. The collection of the landfill gas will reduce the density of methane in the air surrounding the landfill greatly, which improves the air quality in the landfill, Hangzhou City and its surrounding areas.

Due to the reduction of methane density in the air, the probabilities of fire disaster and explosion in the landfill plant and its surrounding areas will drop greatly, which can increase safety and avoid the probable heavy economic damage caused by fire disaster and explosion.

Zhejiang Province is an area with relative developed economy in China, especially in recent years its economy is developing fast. But the natural resources and energy resources of Zhejiang Province are relatively scarce. The energy supply is insufficient and the gap between energy demand and supply depends on allocation and transportation from other provinces. As one of the measures of providing energy supply, the refuse landfill gas generation has a certain effects. In the meantime the implementation of the project can provide about 10 jobs for the local area.

8.6.3 Impact on women work and sanitary conditions

The effective utilization of landfill gases will improve the environment of the plant and its surrounding areas, relieve the problem of foul smile caused by the landfill plant greatly, ease the condition of the propagation of flies and mosquitoes, ameliorate the living conditions of the surrounding areas and reduce the diseases.

8.7 Conclusion and Suggestion

(1) The Project of refuse landfill gas recovery and utilization is a project with dual environmental benefits. Residents don't wish the refuse dump near their houses, so the trend is that the municipal residential solid refuse spread towards rural areas, which pollute the environment, occupy a large amount of soil resources. Therefore, the centralization of refuse dump and disposing and building refuse dispose projects which cause no pollution to the environment are the tendency which will be followed in the near future. On the one hand, the landfill gas for power generation project solves the environmental problems caused by direct emission of landfill gas, realizing the refuse dispose with no pollution to the environment. On the other hand, it makes full use of the resources, achieving a certain of energy benefits. It is one of the measures that intent to solve the problems of landfill gas in landfills, significant

for improving environment, favorable for social development and valuable for dissemination.

(2) From the view of single point of finance analysis, the landfill gas recovery and utilization project isn't a project with economic benefit. But from the point of public welfare or national economic analysis, the project certain vitality.

Moreover, many factors, such as whether the government will provide financial favorable policies on taxation, loan credit, subsidy, etc. and the favorable degree of the policies, whether the project can achieve support of capitals or loan with low interest rate, interest free loan from international organizations, have great influences on the economic benefits of the project. That is, the financial benefits of the project to some extent depend on the incentive policies of central and local governments. So formulating rational incentive policies is an important presupposition for the development and wide dissemination of the project.

(3) In this project, the change of electricity sale has great effect on its economic benefit. Therefore the project manager should coordinate with the electric power sector, to guarantee the electricity generated with landfill gas for its successful connection to the grid, and to sell the electricity at negotiated rational price. In this aspect, relative measures should be taken to encourage the electric power sector to buy the electricity generated by landfill gas, to provide policies, to reduce the risks of this type of project, and to raise the initiative of the landfills, plant or the enterprise to participate in this type of projects.

Annex Table 1

Financial cash flow (including VAT and income tax, inflation) (1000 *Yuan*)

Year	Power sale	Investment	Operating cost	VAT & VAAT	Depreciation	Profit (exclude tax)	Income tax	Net benefit
0	0.0	20,750						20,750.0
1	5,106.9		2,100	471.9	2,075	460.1	151.8	2,383.3
2	5,362.3		2,205	495.5	2,075	586.8	193.7	2,468.2
3	5,630.4		2,320	520.2	2,075	719.9	237.6	2,557.3
4	5,911.9		2,430	546.2	2,075	859.7	283.7	2,651.0
5	6,207.5		2,550	573.5	2,075	1,006.4	332.1	2,749.3
6	6,517.9		2,680	602.2	2,075	1,160.5	383.0	2,852.5
7	6,843.8		2,810	632.3	2,075	1,322.2	436.3	2,960.9
8	7,186.0		2,950	664.0	2,075	1,492.1	492.4	3,074.7
9	7,545.3		3,100	697.1	2,075	1,670.5	551.3	3,194.2
10	7,922.5		3,260	732.0	2,075	1,857.7	613.1	3,319.7
11	8,318.7		3,420	768.6		4,129.4	1,362.7	2,766.7
12	8,734.6		3,590	807.0		4,335.8	1,430.8	2,905.0
13	9,171.3		3,770	847.4		4,552.6	1502.4	3,050.3
14	9,629.9		3,960	889.8		4,780.3	1,577.5	3,202.8
15	10,111.4		4,160	934.2		5,019.3	1,656.4	3,362.9
16	10,616.9		4,370	981.0		5,270.2	1,739.2	3,531.1
17	11,147.8		4,580	1,030.0		5,533.8	1,826.1	3,707.6
18	11,705.2		4,810	1,081.5		5,810.4	1,917.4	3,893.0
19	12,290.4		505	1,135.6		6,101.0	2,013.3	4,087.6
20	12,905.0		5,310	1,192.4		6,406.0	2,114.0	4,292.0
Total	168,865.6	20,750.0	69,438.5	156,024	20,750	63,074.7	20,814.7	42,260.1
NPV	-1,636.2 (15 years)							633.2 (20 years)
FIRR	10.413% (15 years)							12.493% (20 years)

Annex Table 2

Economic cash flow (including inflation) (1000 *Yuan*)

Year	Power sale	Investment	Operating cost	Net benefit
0	0.0	20,825		-20,825.0
1	9,320.6		2,750.0	6,570.6
2	9,786.7		2,887.5	6,899.2
3	10,276.0		3,030	7,244.1
4	10,789.8		3,180	7,606.3
5	11,329.3		3,340	7,986.7
6	11,895.8		3,510	8,386.0
7	12,490.5		3,690	8,805.3
8	13,115.1		3,870	9,245.6
9	13,770.8		4,060	9,707.8
10	14,459.4		4,270	10,193.2
11	15,182.3		4,480	10,702.9
12	15,941.5		4,700	11,238.0
13	16,738.5		4,940	11,799.9
14	17,575.5		5,190	12,389.9
15	18,454.2		5,440	13,009.4
16	19,376.9		5,720	13,659.9
17	20,345.8		6,000	14,342.9
18	21,363.1		6,300	15,060.0
19	22,431.2		6,620	15,813.0
20	23,552.8		6,950	16,603.7
total	308,195.9	20825	90,931.4	196,439.5
NPV	33,383.7 (15 years)			42,163.0 (20 years)
EIRR	35.893% (15 years)			36.383% (20 years)

PART THREE USERS SURVEY ANALYSIS

CHAPTER 9 Analysis of Users of Biomass Gasification System of Central Gas Supply

9.1 The Objective and Sample

The main objective of the sample survey is to identify the availability of biomass resources, the household energy consumption, and their attitude toward the biomass gasification system, then to project the development potential of biomass gasification system in rural areas.

The sample village is Tengzhai village, Huantai County, Shandong Province, where the biomass gasification system has been operating. The sample survey is conducted for the 30 households which are selected by using random sampling approach. The data resulted from questionnaire is processed by SPSS for Windows 6.0.

9.2 The Situation of the Sample Village

9.2.1 The natural and geographic situation

Tengzhai village belongs to Huantai County, located in the middle of Shandong Province, at the South of Lubei Plain. It belongs to temperature monsoon climate zone, the annual non-frost period is about 220 days, the annual average temperature is 12.5°C, and the annual precipitation is 586.4 mm. It is the second village in Huantai County that has built its biomass gasification system.

9.2.2 The social and economic situation

There are 216 households in Tengzhai village, with 800 population. There are farmland of 1,200 *mu*, seven village-enterprises employing 500 workers, of which 2/3 are local farmers.

9.2.3 Population situation

The frequency analysis is shown in Table 9.1.

Table 9.1 The number of family members

Member	Households	Percentage
2	1	3.3%
3	14	46.7%
4	13	43.3%
5	1	3.3%
6	1	3.3%

The number of most family member in the sample is 3-4. It presents the current trends of smaller families, due to the implementation of the birth-control policy since the 1970s.

9.2.4 Income level and source

1) Income level

The annual income per household:

Income(*Yuan*)	Households	Percentage
5,000~10,000	15	50%
10,000~15,000	10	33.3%
15,000~20,000	3	10%
20,000~30,000	1	3.3%
>30,000	1	3.3%

The annual income of most (83.3%) households is in the range of 5,000 and 15,000 *Yuan*. The frequency analysis of annual income per capita is shown in Table 9.2.

Table 9.2 The annual income per capita

Income per capita (*Yuan*)	Households	Percentage
<2,000	2	6.7%
2,000~2,499	4	13.3%
2,500~2,999	9	30.0%
3,000~3,499	7	23.3%
3,500~3,999	2	6.7%
4,000~4,499	3	10.0%
4,500~4,999	0	0.0%
5,000~5,999	1	3.3%
6,000~6,999	1	3.3%
7,000~7,999	1	3.3%

The annual income per capita of most households is around 2,000 and 3,500 *Yuan* (see Figure 9.1a for details). The arithmetic means of the sample is 3,297 *Yuan*.

2) Income source

The main income source of the farmers is the salary from the local enterprises, since about 42% of the farmers work in the TVEs, shown in Figure 9.1b.

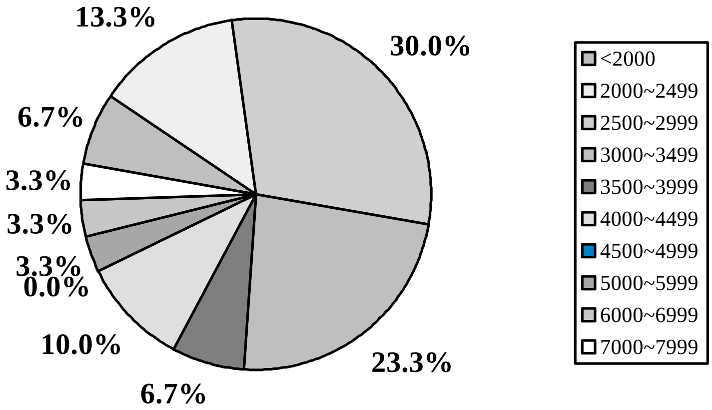


Fig. 9.1a Annual income per capita

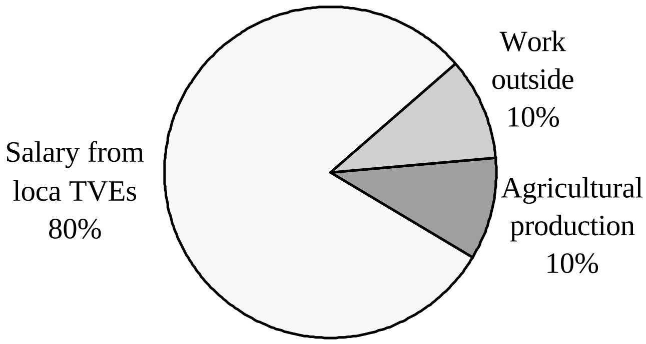


Fig. 9.1b Income source

9.2.5 Education of the host in the families

Table 9.3 Education of the host in the families

Education	Households	Percentage
High school	4	13.3%
Middle school	14	46.7%
Primary school	12	40%

It has been indicated that 60% of the host member has been educated to the level of middle school or higher, and the rest has been educated to the level of primary school.

9.3 Availability of Biomass Resources

9.3.1 The straw production and its category

Tengzhai village is located in the plain area of northern China, the main crops are wheat and corn, harvested in summer and fall respectively. So their straw can be supplied to the gasification system. The average straw production per *mu* could be calculated by using weighted mean approaches.

- Ratio of straw and grain, straw:wheat = 1:1, and straw:corn = 2:1,
- Area of cultivated land: 166.5 *mu* (11 hectare)
- Wheat straw: 76,017 kg/yr
- Corn straw: 185,492 kg/yr

The average production of straw from wheat is: 456.6 kg/*mu* from wheat, and 1,114.1 kg/*mu* from corn.

9.3.2 The ways of straw utilization

- Fuel: corn straw (27 households)
- Sale: corncob (27 households)
- Fertilizer: wheat straw (29 households)

The straws are mostly used for fuel, sale and fertilizer, not for fodder, based on their nature respectively, as the main economic activities in the village are grain production and village-enterprises production, with some stockbreeding.

9.3.3 Population determination

There are 1,200 *mu* of farmland in the village, of which 1,100 *mu* are planted with wheat and corn. Therefore, the total biomass resources available for the village can be evaluated as follows:

Corn straw production = sample averaged production per *mu*×Cultivated area
=1,114.1 × 1,100 =1,225,510 kg
Wheat straw production = sample averaged production per *mu* * Cultivated area
=456.6 × 1,100 =502,260 kg

According to the current grain production scale, there are 1,225.5 tons of corn straw and 502.3 tons of wheat straw available for the biomass gasification system annually. The total amount is 1,727.8 ton.

9.4 Energy Utilization Analysis

9.4.1 Fuel for cooking

Now, almost all households use coal and straw gas for cooking, only a few households still use straw and LPG.

Table 9.4 The current fuel category for cooking for the sample

Fuel for cooking	Households	Percentage
Coal	30	100%
Straw	1	3.3%
LPG	1	3.3%
Straw Gas	28	93.3%

9.4.2 The change of energy in the future

From the returned questionnaires, it can be seen that all households only selected electricity for cooking in the future. Because it is convenient, clean, and quick, farmers are usually interested in electricity. Also, the current price of electricity in Tengzhai village is 0.5 *Yuan*/kWh, which the farmers can afford.

9.4.3 The cost of fuel

The current annual cooking fuel cost per household is 530.5 *Yuan*, and the annual fuel cost per capita is 153.4 *Yuan*, which is mainly for coal.

9.5 Analysis on the Attitude to Investment in the Gasification System

9.5.1 The attitude toward the gasification system installation

It is apparent from Table 9.5 that all the households support building the gasification system. About 86.7% of the households support strongly and provide financing actively.

Table 9.5 The attitude to the gasification system installation

Attitude	Households	Percentage
Support and financing actively	26	86.7%
willing, but short of fund, need subsidy	4	13.3%

9.5.2 The advantage of straw gas in comparison with the past energy utilization pattern

Table 9.6 Comparison between straw gas, coal and LPG

	Compared with coal (%)			Compared with LPG (%)		
	Better	Same	Worse	Better	Same	Worse
Price	100	0	0	100	0	0
Convenience	56.7	43.3	0	6.7	93.3	0
Reliability of supply	16.7	83.3	0	0	100	0
Environmental impact	96.7	3.3	2.5	53.3	46.7	0
Working intensity of housewives	100	0	0	50	50	0

9.5.2.1 *Compared with coal*

It can be seen from Table 9.6 that except for reliability of supply, straw gas has obvious advantages than coal.

- Reliability of supply: 83.3% of households think that there is no difference between straw gas and coal;
- Price, convenience, environmental impact and working intensity of housewives: straw gas has some advantages, especially obvious on price and working intensity.

9.5.2.2 *Compared with LPG*

The statistical result of table 9.6 shows that compared with LPG, straw gas still has some advantages.

- Price: Absolute advantage.
- Convenience and reliability of supply: no obvious difference appears.
- Environmental impact and working intensity of housewives: The percentage of "Better" and "Same" is nearly 50% respectively, it can be concluded that straw gas has been accepted by more households.

As the gas fuel, the straw gas and LPG have many denominators, but the raw material for straw gas is the crops' straw, which is very cheap. Therefore, the production cost of straw is much lower than that of LPG. Furthermore, the straw gas can reach the kitchen directly through the pipeline, the working intensity of housewives can be alleviated.

9.5.3 Financing situation

Table 9.7 The financing capability of the households

Amount (*Yuan*)	<500	500~1,000	1,000~2,000
Households	17	12	1
Percentage	56.7%	40%	3.3%

9.5.4 Assessment on the current gasification system

- Gas supply service hour: the current 2-3 hours per day is appropriate to the sample;
- Service quality: satisfied by households, due to regular maintain for the stoves, meters, de-SO_x filters and pipeline and quick repair upon request.

9.5.5 Correlation analysis

Income-Attitude

The Pearson correlation coefficient of the annual income per capita and the attitude to gasification system is 0.816, and the coefficient of the annual income per household and the attitude also reaches 0.723. The attitude and the income has positive linear correlation, that means that the more income the sample get, the more actively they support the system.

9.5.6 Attitude to straw gas-fired power generation

Based on the common satisfaction for the biomass gasfication system, all the households of the sample gave their very positive answers to the question "What is your attitude to build a straw gas-fired power station?" to: (1) improve electricity supply, (2)substitute of electricity for coal stoves and gas stoves, (3) utilize the surplus straw.

9.6 Conclusion

1. In order to build a biomass gasification system in north China, the availability of biomass resources could be calculated by the following production data: corn stalks 1,114 kg per *mu*, wheat straw 456.6 kg per *mu*.

2. Along with the development of rural economy, the living standard of farmers also improved. After solving the problem of food supply, farmers begin to pay attention to their life quality, and require more clean, convenient and reliable energy supply for cooking, which could be met by gas fuel at lower price than LPG. So the straw gas is welcomed by farmers.

3. With its enough gas supply and good service quality as well as obvious social benefit, the gasification system in Tengzhai village is quite satisfied by the farmers.

4. Having derived benefits from the gasification system, the farmers are interested in the gas-fired power generation. So it is recommended to build a pilot project of gas-fired power generation at proper place and time.

CHAPTER 10 Analysis of Users of Large-medium Biogas Project for Central Gas Supply

--Xinghuo Husbandry Farm, Shanghai

10.1 The Objective and Sample

The main objective of the sample survey is to identify the household energy consumption and their attitude to biogas project, then to educe the application effect and project the development potential of biogas project system in rural area.

The sample unit is Xinghuo Breeding Farm in Fengxian County, Shanghai. The biogas project was constructed in 1991. The sample survey was conducted for the 50 households, selected at random, and includes a biogas team consists of 40 biogas users and a comparison team consists of 10 LPG users. The data resulting from questionnaire were processed by SPSS for Windows 6.0.

10.2 Basic Situation

10.2.1 Xinghuo breeding farm and its biogas project

Xinghuo breeding farm is located in Fengxian county, Shanghai with 21.67 km^2 areas and 6,600 employees. With a loan from Australia, the Shenxing modernization cattle farm was built in 1989. There are more than 2,000 cows in the farm and the annual dung production is 31,000 ton. In order to solve the problem of pollution and resource utilization, the biogas project was completed in 1991 with 6 digester, the total area of digester and gas storage tank reaches 2,700m^3 and 1,400m^3 respectively. Because the biogas is provided to more than 3,000 households, one restaurant and a hotel, and because the residue is made into high-quality organic fertilizer, there is a significant economic benefit.

10.2.2 Population situation

The population of most households (47 households) is 2-3, about 90% of the sample, and the three-person household is about 75% of the sample. Since Xinghuo farm is located in Shanghai - the top region in Yangzi river economy zone. Along with the development of market economy, the procreation idea of farmer has changed from

"More children, more happiness" to "The one is the best." The sample just incarnates this characteristics (see Table 10.1 for details).

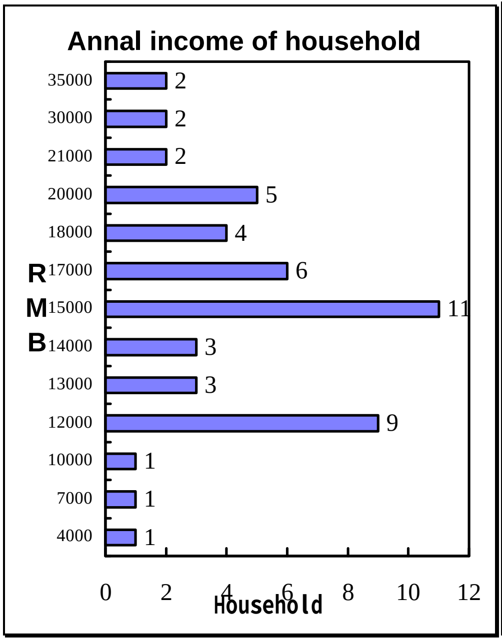
Table 10.1 The household population scale of sample

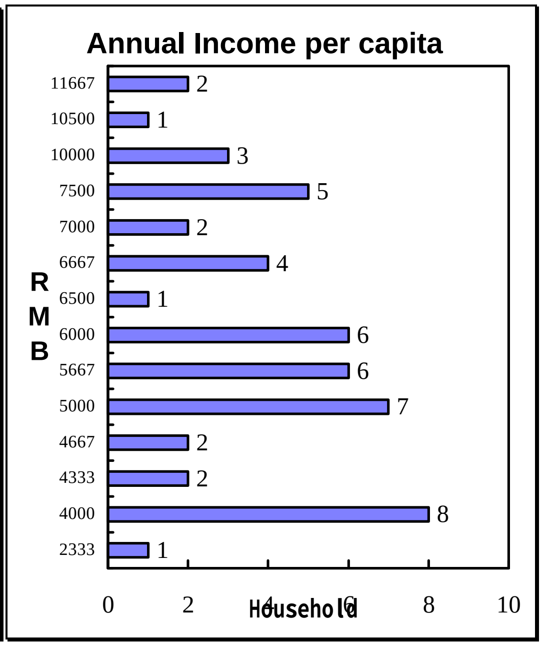
Member	1	2	3	4
Household	2	10	37	1
Percentage	4%	20%	74%	2%

10.2.3 Income level and source

10.2.3.1 *Income level*

The annual income of most households (41 households) is 12,000-20,000 *Yuan*, 82% of the sample, the average income is 16,420 *Yuan* per household. The annual income per capita of 43 households is 4,000-7,500 *Yuan*, about 86% of the sample. The average value weighted by population is 6,000 *Yuan*. The distribution is shown in the chart below.





10.2.3.2 *Income source*

Since all the investigation object are employees of Xinghuo breeding farm, so their income source is the same - local enterprises wage.

10.2.4 Education level of householder

About 72% of the householders were educated at the junior and senior high school levels; four householders received higher education, but there are still three illiterate householders. See Table 10.2 for detailed distribution.

Table 10.2 Education level of householder

Education level	Junior college or higher	Technical school and senior high school	Junior high school	Primary school	illiteracy
Household	4	18	18	7	3
Percentage	8%	36%	36%	14%	6%

10.3 Energy Utilization Analysis

10.3.1 Current energy for cooking

10.3.1.1 *Biogas team*

Since the biogas project in Xinghuo farm was completed and started to provide biogas at the end of 1991, so the energy for cooking of households in biogas team is biogas from 5 years ago.

10.3.1.2 *Comparison team*

Different from the situation of biogas team, the energy for cooking of comparison team are LPG and electricity; and the situation 5 years ago was: LPG and electricity for 80% households, biogas and electricity for 20% households in the comparison team.

10.3.2 The change of energy in the future

From the returned questionnaires, it can be seen that all households in biogas team only selected electricity for cooking in the future, and 85% of households in comparison team selected biogas too.

10.3.3 Cost of fuel

Based on the current price of biogas which is 1.2 *Yuan*/m^3 and 37*Yuan*/bottle of LPG, the annual fuel cost average per household is 338.7 *Yuan* for biogas team and 388.5 *Yuan* for comparison team, which is a little higher than that of biogas team.

10.4 Analysis on the Attitude to Investment in the Biogas Project

10.4.1 The attitude to the biogas project construction

Both biogas team and comparison team have a supporting attitude to the biogas project construction, the percentage of households which will “support strongly and finance actively” reaches 92.5% and 70% in biogas team and comparison team respectively; only one household thinks that it is unnecessary to build a biogas project.

10.4.2 Capability of investment

Although most household in the sample will "support strongly and finance actively" to the biogas project construction, but investment capability of 88% of households is not very high, less than 2,000 *Yuan*; only 1 household can invest more than 3,000 *Yuan*.

10.4.3 The advantage of biogas in comparison with the past energy utilization pattern

10.4.3.1 *Compared with coal*

It can be seen from Table 10.3 that except for price and reliability, biogas has obvious advantages than coal.

- Price: 60% of households think the price of biogas is similar to that of coal, but 27.5% of households think that biogas is a little expensive than coal;
- Reliability of supply: All the 40 households in biogas team think the reliability of supply of biogas and coal are same;
- Convenience, environmental impact and working intensity of housewives: Biogas has some advantages.

Table 10.3 Comparison between biogas, coal and LPG

	Compared with coal (%)			Compared with LPG (%)		
	Better	Same	Worse	Better	Same	Worse
Price	12.5	60	27.5	100	0	0
Convenience	30	70	0	97.5	2.5	0
Reliability of supply	0	100	0	5	95	0
Environmental impact	47.5	50	2.5	92.5	7.5	0
Working intensity of housewives	60	40	0	100	0	0

10.4.3.2 *Compared with LPG*

The statistical result of Table 10.3 shows that compared with LPG, biogas has absolute advantages on all aspects except the reliability of supply.

- Reliability of supply: 95% of households selected "Same," it seems that there is no difference on reliability of supply between them.
- Other aspects: The advantages of biogas are very obvious, the percentage of "Better" selection is over 90% on all the four aspects.

10.4.4 Assessment on the current biogas project

Table 10.4 Users assessment on the current biogas project

Biogas supply		Suitable: 100%	
Service quality	equipment check	regularly: 47.5%	not regularly: 52.5%
	equipment repair	quick repair: 45%	can repair: 55%
Price	1.2*Yuan*/m^3(now)	reasonable: 45%	expensive: 55%
	1.0*Yuan*/m^3	reasonable: 55%	expensive: 45%

The following conclusions can be drawn from Table 10.4.

- Gas supply service hour: the current 2-3 hours per day is appropriate to the sample;
- Service quality: satisfied by households, due to regular maintain for the stoves, meters, de-SO_x filters and pipeline and quick repair upon request;
- The biogas supply quality of the biogas project in Xinghuo farm is comparatively high and satisfies the users;
- On the aspect of service, the households in biogas team think that the service is comparatively good;
- Price: The current price - 1.2*Yuan*/m^3 has not been accepted by all the households. 55% of households think the price is a little higher and it is difficult

for them to afford; if the price can be reduced to 1.0 *Yuan*/m^3, it can be acceptable.

10.4.5 Attitude to biogas power generation

All the households (both in biogas team and comparison team) think that it is unnecessary to build a biogas power generation project because the current grid is operating stable, biogas power generation project is unnecessary.

10.5 Conclusion

- Since Xinghuo breeding farm is located in the well developed area in east China, so the households in sample have comparatively small population scale and high annual income, about 6,000 *Yuan* per capita.

- Compared with traditional energy for cooking such as coal and LPG, biogas is commonly thought to have comparative advantages, especially on the aspects of convenience, environment impact and working intensity of housewives. But on the aspects of price and reliability of supply, there is no significant difference between biogas and coal and LPG.

- As the demonstration project involved in the "Ninth Five Year Plan," the biogas project in Xinghuo breeding farm has operated stable for 6 years. Not only its gas supply and service quality have reached comparatively high level, but also well social, economic and environmental benefits are received. If the gas price can be properly adjusted (0.2 *Yuan*/m^3 lower than before), the biogas project will be much more popular.

- Because farmers derived many benefits from the biogas project, so they all have the active attitude to the construction of biogas project. The maximum investment of a household in sample is 2,000 *Yuan*, about 1/8 of the annual income per household.

- Although the biogas project is well satisfied by biogas team and even eagerly expected by comparison team, but it is still unnecessary to build biogas power generation system in areas where the grid is stable operating.

PART FOUR APPENDIX

APPENDIX I Brief Introduction of Methodology of Techno-economic Assessment

The Project Techno-economic Assessment is one of the important components of the project feasibility, which aims at calculation of the invested costs and profits of the project based on the program comparison of the project techniques such as project scale, site selection, processes etc. It includes the financial assessments and national economic assessment. The financial assessment is the calculation of the profit and cost within the project under the condition of the state current tax system and price system, and the analysis of the profitability and liquidation of the project, For the purpose of investigation of the financial feasibility of the project. The national economic assessment is the analysis of net project contribution to the national economy from the macro point of view of the state with the consideration of rational allocation of the national resources for the purpose of the investigation of economic rationality of the project.

Generally speaking, if both of the financial assessment and the national economic assessment of a project are feasible, the project could be authenticated, otherwise the project could be rejected. If the national economic assessment is not feasible, usually it could not be supported.

1. Financial Assessment

1.1 financial profit and cost

The projects' profit is mainly the sales income of the product. Other incomes include the reduction of environment penalty before and after the operation of the project, and the actual incomes from comprehensive utilization such as the sales income of the digested materials as fertilizers in the biogas project.

The expenditure is principally the project investment, the flow cash, the operation cost as well as the tax that should be paid. See Table 1, 2, 3.

Table 1 Fixed Assets Investment Budget

Item	Annual investment			
	1st Year	2nd Year	3rd Year	......
Material-collecting System				
Pretreatment Equipment and Installation				
Main Productive Systems				
H_2S Removing Device				
Gas Storage				
Post Treatment Equipment& Installation				
Pipe Network Cost				
Other Cost				
Total				

Table 2 Cost Budget

Item	Products		
	A	B	......
Annual Output			
Operational Cost			
Among which: Depreciation			
Maintenance			
Material			
Fuel & Power			
Wages			
Other			
Management Cost			

Table 3 Loss and Profit

Item	Construction Period			Productive Period					Total
	1	2	3	4	5	6	......	n	
Output									
1) Sales Income									
2) Total Cost									
3) Taxes									
4) Sale Profit =1)－2)－3)									
5) Other Expenditure									
Profit Amount =4)－5)									

1.2 Financial analysis

It is the analysis of financial profitability including the calculation of the indexes of the financial internal rate of return, payback period of the investment, financial net present value, financial net value rate, investment profit rate and investment tax rate. The major assessment indexes are the financial internal return rate and payback period of investment. According to the requirement of the assessment analysis, the calculation of the financial net value, the investment profitability and investment tax rate could be used as auxiliary indexes.

- ***Financial internal rate of return*** **(FIRR)**

FIRR is the major index for the assessment in the measurement of the financial feasibility, and the discount rate when the annual present value of the net cash flow accumulated to be zero in the calculation period of the project. Usually, FIRR≥the industrial basic discount rate, it shows it is feasible in project finance, which could be shown in the formula as the follows:

$$\sum_{t=1}^{n}(CI-CO)_t(1+FIRR)^{-t}=0$$

Where, CI : Cash inflow (including sales income, surplus value of fixed assets return, flow cash return);

CO : Cash outflow (including the investment in the fixed assets, flow cash, operation costs and taxes);

$(CI\text{-}CO)_t$: The net cash flow of the *t* year;

n : Calculation period of the project.

Financial Internal Rate of return could be computed, in the way of trial calculation method in accordance with the net cash flow in the financial cash flow statement. In the trial calculation, when the sum of the present value of the net cash flow changed from the positive to the negative one, it indicates that the zero value is just between the two adjacent discounts. It could be consulted from the following formula:

FIRR = Discount 1 + [net present value 1 / (net present value 1 + net present value 2)]× (discount 2 - discount 1)

- ***Financial Net Present Value*** (**FNPV**)

FNPV is the sum of present value discounted by net cash flow in the calculation period of the project to the initial period of the project construction, the higher its value is, the more profitable the project would be. It could be shown in the following formula:

$$\mathrm{FNPV} = \sum_{t=1}^{n} (\mathrm{CI} - \mathrm{CO})_t (1 + i_c)^{-t}$$

Where, i_c : the industrial basic rate of return affiliated to the project.

- ***Payback Time of the Investment (Pt)***

Pt or investment principal returning time is the time necessary for the net return of the project to setoff the whole investment (including the fixed assets investment and the flow capital). To consult the comparison between the investment payback time and the industrial basic investment payback time by means of the calculation of the accumulated net cash flow inside of the financial cash flow statement, which reflects the important index of the financial investment return ability for the project. The formula is shown as the following:

$$\sum_{i=1}^{Pt} (\mathrm{CI} - \mathrm{CO})_i = 0$$

Where, Pt: investment payback time, is indicated by annual.

Table 4 Cash Flow(Finacial)

No.	Item	Construction Period			Productive Period				Total
		1st yr	2nd yr	3rd yr	4th yr	5th yr	6th yr	... n	
	Output								
1)	Cash Inflow Product Sale Income Original Value of Fixed Assets Return Flow Cash Return Sub-total								
2)	Cash Outflow Fixed Assets Investment Flow Cash Management Cost Taxes Interest Payment Other Expenditure Sub-total								
3)	Net Cash Flow=1)－2)								
4)	Collected Cash Flow								
5)	Calculation Index: Financial Internal Rate of Return Financial Net Present Value Payback Time of Investment								

2. National Economic Analysis

The national economic assessment is the investigation of the projects' profits and costs and the calculation and analysis of the projects' net benefit to the national economy by means of shade price, opportunity cost as well as social discount rate, so as to assess the economic rationality of the project.

2.1 Profit and Cost of the Project

- ***Direct profit and in-direct profit***

Direct profit : it is the economic value of the output product of the project by means of shade price calculation, e.g. in the biogas project, the direct profit is the biogas, animal feed, and fertilizer etc.

Indirect profit : that part of the profit which could not be obtained by the project itself, i.e. the social contribution made by the project, such as the improved air quality by implementing crop stalks gasification, sanitary conditions and women labor strength etc.

- ***Direct cost and indirect cost***

Direct cost : it is the economic value of the project investment calculated by means of shade price, e.g. the fixed assets investment, a flow fund and operational cost etc.

Indirect cost : it refers to that part of cost, which is not necessary for the project to pay but is paid to the project by the society.

- ***Tax and subsidy***

The tax and subsidy directly relating to the project are not calculated as the project cost and profit due to the fact that they will not realize the increase and consumption of the actual resources and the fact that they belong to the internal transfer payment within the national economy.

2.2 National Economic Analysis

- ***Economic Internal Return Rate (EIRR)***

It refers to the discount rate when the net present value accumulated in the calculation period of the project to be zero, which reflects the contribution to the national economy by the project. EIRR>=social discount indicates that the project is economically feasible. It can be expressed as follows:

$$\sum_{t=1}^{n}(B-C)_t(1+EIRR)^{-t}=0$$

where, B : profit flow amount calculated by shade price ;
C : profit flow amount calculated by shade price;
$(B-C)_t$: the net cash flow of the t year;
n : calculation period.

- ***Economic Net Present Value (ENPV)***

It is the sum of the present value of the initial period of the first year for the project start discounted from the annual net profits of the project calculation period by means of social discount rate, whose formula is like this:

$$ENPV=\sum_{t=1}^{n}(B-C)_t(1+i_s)^{-t}$$

Where, i_s : social discount, of which the data is stipulated and promulgated by the China State Planning Commission.

3. Sensitivity Analysis

It refers to analysis and prediction of the impact of the financial economic assessment of the major changing factors of the project, so as to find out the sensitive factors and determine the impact levels, analyzing the possible impact of the mentioned factors to the project in the future (See Table 6). The major factors affecting the project are as the follows: the fixed assets investment, operational cost, product price, product output capacity, environment penalty etc. Analysis is made on the impact of the internal return rate when the single factor or multiple factors are changing simultaneously. If necessary, the impact on the investment payback time needs analyzing as well.

Table 5 National Economic Benefit- Cost Cash Flow

No.	Item	Construction Period			Productive Period				Total
		1	2	3	4	5	6	... n	
	Output								
1)	Cash Inflow Project Income Original Value of Fixed Assets Return Flow Cash Return External Benefit Sub-total								
2)	Cash Flow Fixed Assets Investment Flow Cash Operational Cost Other Expenditure External Cost of Project Sub-total								
3)	Net Cash Flow=1)－2)								
4)	Calculation Index: EIRR Net Present Value								

Table 6 Sensitivity Analysis

Factor	variation rate	-20%	-10%	0%	+10%	+20%
investment	IRR					
operating cost						
gas price						

APPENDIX II General Procedure of Applying for Loan in China

In order to satisfy the demand of further development of reformation, a series of reformation policies have been implemented by government of China since 1993, include:

(1) People Bank of China(PBC) became the genuine central bank, takes charge of the monetary policy and management and supervision of financial business
(2) Three policy banks founded from the national commercial banks,they are:
    State Development Bank of China(SDBC)
    Agricultural Development Bank of China(ADBC)
    Export and Import Bank of China.
(3) National bank became the genuine commercial bank, such as: Industry and Commercial Bank of China(ICBC), Agricultural Bank of China(ABC), Bank of China(BOC), Construction Bank of China(CBC), Communication Bank of China.
(4) Single exchange rate of RMB, loan quota cancel.

Generally, in order to get loan from bank, the project need to be classified and then declared step by step.

The infrastructure projects need be reported to State Development and Planning Commission through planning division of the relevant leading department of their trades at the central level. The provincial projects need be reported to the State Development and Planning Commission through provincial Planning Commission. State Development and Planning Commission will only censor whether the project accords with the nation's industry policy or not, not the fund source. The final representative of the loan negotiation is the People Bank of China(PBC). State Development and Planning Commission will also take part in the negotiation of important projects.

For the energy conservation and technology reformation projects, feasibility report should be prepared by the project management division and then submitted to the county and provincial charge departments and relevant banks for approval; only after approved by the charge department of the central government and the Head Office of the bank, can the project begin to implement.

There are different type of foreign loan. One is governmental bilateral mix loans, which normally no less than 100 million US$ (40% of foreign currency and 60% of local currency), and based on the negotiation between the Ministry of Foreign Economic and Trade and foreign government. The PBC is in charge of the financial contract signment. The different department can apply for the soft loan, commercial loan and foreign exchange loan with no more than 5 projects every year. The second one is multilateral loans under the following procedure:

- project preparation
- review
- assessment
- negotiation between PBC and the relevant bank or government
- execution.

The procedure for loan application will take 2 years from the preparation till the execution with no less than 40 million US $. The implemention agency may be a financial intermediary , the local government or the industry.There is neither a standard nor the index system on how to select the financial intermediary and bank. But, the financial intermediary must be involved in the negotiation with the foreign bank . The foreign bank can even select the financial intermediary by themselves.

For rural project, the major domestic intermediary bank are ABC, ADBC and CBC. The non-bank financial agency may be China Agricultural Development Trust and Investment Company(CADTIC) and Agricultural Cooperation Bank (ACB). In China, the rural energy and renewable energy projects have been supported by some important banks such as ABC, ICBC, CBC etc., which have been profitable from loan.

The procedure above is valid before January 1, 1998. Any changes are not clear, since the financial system reform is undertaking.

APPENDIX III

Main Equipment Producer of Large-medium Breeding Farm Biogas Project

Product or Equipment	Producer	Address
Weed eliminator	Liuhe water purifier plant	
Incision pump	Shanghai No.5 vehicle fittings plant	Shanghai
	Jinhui co-management plant	Shanghai
Material pump	Shanghai light-industry machinery equipment plant	Shanghai
Slurry pump	Xianfeng farming machinery manufacture plant	Shanghai
Pressed pour pump	Shijiazhuang pump plant	Shijiazhuang, Hebei
Anaerobic digest tower	Chengdu biogas research institute, MOA	Chengdu, Sichuan
	Hangzhou energy environment technology corporation	Hangzhou, Zhejiang
	Shanghai Sanxing energy and environment protection engineering company	Shanghai
Lipp ferment tank	Hangzhou energy environment technology company	Hangzhou, Zhejiang
Gas tank	Chengdu biogas research institute, MOA	Chengdu, Sichuan
	Hangzhou energy environment technology company	Hangzhou, Zhejiang
	Shanghai sanxing energy and environment protection engineering company	Shanghai
Seperator of solid and liquid	Shanghai centrifugal machine institute	Shanghai
No-block pump	Beijing agricultural engineering university	Beijing
Biogas engine(100% biogas fired) and Biogas power generator	China Wujin diesel engine plant	Wujin, Jiangsu
	China Sichuan farming machine institute	Nanchong, Sichuan
	China Shanghai agriculture institute	Shanghai
	China Chongqing motor plant	Chongqing
Biogas engine(100% biogas fired) and biogas power generator	Tai'an motor plant	Tai'an Shandong
	China Sichuan farming machine institute	Nanchong, Sichuan
Stainless steel electronic ignition biogas kitchen range	Jiangxi rural energy and environment protection technology development center	Nanchang, Jiangxi
	Jiangxi energy conservation instrument plant	Nanchang, Jiangxi
JZZ biogas kitchen range	Ningbo Yufeng electronic kitchen range plant	Ningbo, Zhejiang

Abbreviation

AF	:	Anaerobic Filter
BOD	:	Biological Oxygen Demand
CAS	:	Chinese Academy of Science
COD	:	Chemical Oxygen Demand
EIRR	:	Economic Internal Rate of Return
FIRR	:	Financial Internal Rate of Return
GNP	:	Gross National Production
HHV	:	High Heat Value
i	:	Discount Rate
IRR	:	Internal Rate of Return
kgce	:	kilogram coal equivalence
LHV	:	Low Heat Value
MOA	:	Ministry of Agriculture
MTCE	:	Million Ton Coal Equivalence
mu	:	Unit of square measure in China, equals to 1/15 hectare, 666.7m^2
NPV	:	Net Present Value
SBP	:	Sludge Bed Pool
SPC	:	State Planning Commission
SS	:	Suspended Substance
Pearson correlation coefficient	:	a coefficient shows the correlation of two variables, the more the value near to 1, the more the two variables correlated closely
TCE	:	Ton Coal Equivalence
TN	:	Total Nitrogen
ton	:	metric ton (1,000kg)
TSP	:	Total Suspended Particle
TVEs	:	Town and Village Enterprises
TVS	:	Total Volatile Solid
UASB	:	Upper Flow Anaerobic Sludge Bed
VAAT	:	Value Added Annex Tax

VAT	:	Value Added Tax
VOC	:	Volatile Organic Compound
VS	:	Volatile Substance
xiang	:	township, a rural administrative unit under the county
Yuan	:	Unit of China money, 1 USD = 8.27 *Yuan*

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